4.0 Pipeline Risk Estimate Calculations

This section of the Protocol presents the methodology and data needed to prepare a pipeline risk analysis. General principles of the Protocol methodology are discussed followed by the specific equations and data required to prepare an analysis. A numerical example is presented to illustrate the method. As with other parts of this Volume of the Protocol, reference is made to Volume 2 for more details on specific topics.

The Protocol uses the classic concept of Individual Risk (IR) as the basis for the risk analysis method. The definition in this Protocol is that the IR is the annual probability of a fatality to an individual at a specified location for a defined occupancy period in the course of a year, from a specified hazard. The Protocol methodology estimates an IR value for a point location at a specified distance from the pipeline segment that lies within 1,500 ft of the school campus site property boundaries. The methodology in the Protocol can also be easily adapted to estimating the location at which a specified IR value will occur. The fundamental approach to risk estimating is based on principles established in the technical literature for accidental chemical releases. A foundation document is the "Brown Book" issued by the Federal Emergency Management Agency (FEMA), the U.S. Environmental Protection Agency (EPA), and the U.S. Department of Transportation (DOT) for emergency planning (FEMA 1989). Other significant documents include the classic book by Lees, *Loss Prevention in the Process Industries* (Lees 1996), and various publications by the Center for Chemical Process Safety (CCPS) of the American Institute of Chemical Engineers (CCPS 1989, 1992, 1994, 1996). Adaptations of these principles have been made specifically for pipelines in the context of this Protocol.

A fundamental premise of this Protocol is to present an estimating method that is simple while still providing reasonable risk estimates for policy decisions. The calculations are based on certain assumptions that, by definition, are part of the Protocol. The estimates provide values that are intended for comparison with a numerical Individual Risk Criterion (IRC) specified by CDE. An IR of 1.0E-06 (one chance in a million each year) has been selected based on regulatory practice for the siting of industrial facilities with hazardous chemicals in the United Kingdom and the Netherlands. In those cases, the IR concept is used as a criterion for determining whether additional mitigation is needed when government authorities are evaluating an industrial asset site. While the situation here is the reverse, siting a school campus site near an existing industrial asset, the risk principles are similar, and CDE concluded that the same criterion is appropriate. If values computed by a standard method described in the Protocol, or similar and well-documented methods, meet the specified criteria, then the proposed school campus site has met the regulatory expectations.

The general risk evaluation approach consists of the following steps:

1. Data collection and system definition;
2. Risk estimation; and
3. Reporting.

This section focuses on the risk estimation and demonstrates the method through an example. Data collection forms and reporting requirements are presented in Section 5.

4.1 Applicability

A pipeline risk analysis may be required for either a land or building expansion of an existing school facility or for a new school campus site that lies within 1,500 feet of a pipeline operating at a pressure of 80 psig or higher, according to Title 5 Site Selection standards or CDE plan submittal and certification requirements. The requirement covers pipelines carrying chemical products, natural gas, and other hydrocarbon products. CDE has determined that high capacity water lines are also included, but the approach in evaluating them is different, as discussed later in Section 4.

4.2 General Data Requirements

The data required for a risk analysis include pipeline data and campus site data. Some information that would aid in a risk analysis is proprietary to the pipeline operator. A LEA risk analysis usually must rely on publicly available information.

In general, the required data include:

- The location of the proposed school campus site, including roads and major terrain feature boundaries;
- The location of the pipeline with respect to the proposed school campus site, and specifically the segment lying within the 1,500-foot boundary zone;
- Land use and terrain characteristics adjacent to and within the 1,500-foot zone;
- The pipeline diameter, operating pressure, and for liquid pipelines, the product flow rate; and
- Pipeline operating history information, especially records of any previous accidental releases of product and the repair history, if available.

A Phase I Environmental Assessment study will sometimes have identified hazardous material pipelines near a campus site and several key characteristics of a pipeline such as:

- Location;
- The product transported;
- Diameter;
- Operating pressure;
- Materials of construction; and
- Date of construction.

The environmental setting and campus site description will sometimes have also been discussed in the Phase I Environmental Assessment Report (EAR). Where a Phase I EAR does not contain the required information or has not been completed before a pipeline risk analysis is needed, other sources of information must be used. In cases when not all necessary pipeline data can be obtained by the risk analyst, reasonable estimates or worst case assumptions may be appropriate.

Sources of data other than a Phase I assessment are geohazard reports, environmental impact reports, the pipeline operator's records and public records from the Federal Office of Pipeline Safety (OPS) or state agencies. California state agencies include the Office of the California State Fire Marshal, Pipeline Safety Division (hazardous liquid pipelines); the California Public Utility Commission (natural gas pipelines); the California Department of Conservation, Division of Oil, Gas and Geothermal Resources (DOGGR) (natural gas wells), and the California Department of Fish and Game, Office of Spill Prevention and Response. DOGGR regulates oil and gas fields and has information related to gathering systems. The Office of Spill Prevention and Response has emergency response plans from pipeline operators. Operating permits filed by pipeline operators with State authorities might also contain some of the location and pipeline specifications information needed for a risk analysis.

Information that is in the public record should be compiled before contacting the operator. It is advisable to seek as much information as is available from the pipeline operator. The list of risk factors in Appendix A, in the Appendices volume, defines the kinds of information to be sought that would help evaluate the relative likelihood of a failure of the subject system. This provides a basis for potential, informed subjective adjustments to or interpretations of quantitative estimates. An operator might not be able to provide the information requested.

For the two types of pipeline jurisdictions (federal and state), the availability of information depends on whether the particular pipeline is an interstate pipeline under federal jurisdiction or an intrastate pipeline under state jurisdiction. If an operator's pipeline has an accidental release of product (or other incident) that meets certain criteria specified by the federal gas or hazardous liquid pipeline regulations (Title 49, Code of Federal Regulations, Part 192 for gas pipelines and Part 195 for liquid pipelines), the operator must file a report with the OPS detailing information on the pipeline that failed and the nature of the release event. The California State agencies have similar reporting requirements.

4.3 General Description of Approach

A staged approach to risk analysis has been established for the Protocol that allows the LEAs to execute a risk analysis to the degree of detail commensurate with specific situations and consistent with the amount of data and information that is available for the assessment. Three stages are defined as:

- Stage 1 –Risk Screening Analysis
- Stage 2 – Probabilistic Analysis
- Stage 3 – Detailed Probabilistic Risk Analysis

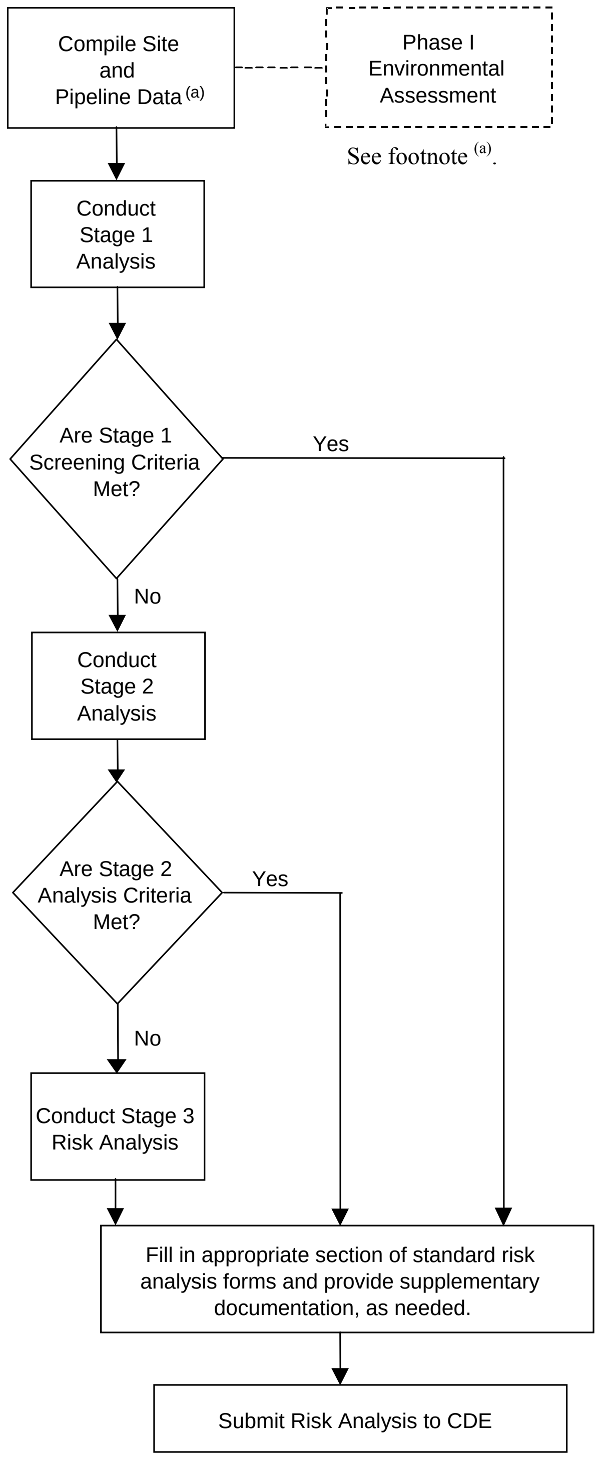
Figure 4-1 illustrates the overall process for a risk analysis. The Stage 1 Risk Screening Analysis (RSA) uses a risk-ranking scheme based on the proposed campus site and the pipeline conditions meeting certain criteria. If the criteria are met, the level of risk is defined based on a pre-analysis of various combinations of these standard conditions. No further analysis is needed.

If the screening criteria are not met, the proposed campus site is subject to a Stage 2 analysis. A Stage 2 risk analysis yields a calculated IR estimate for a campus site. The IR value is the probability of fatality of an exposed individual at a specified receptor location. CDE specifies an IR maximum criterion of 1.0E-06 at the center of the property line nearest the pipeline, or at the boundary between the usable and unusable portion of when the unusable portion is on the side facing the pipeline. If the estimated IR exceeds this value additional mitigation is expected or a more detailed IR analysis is called for. In some cases where there are large unusable portions of the school site, the CDE IR criterion might be met at the usable portion of the site nearest the pipeline.

The Stage 1 and 2 methods provide a level of analysis based on certain assumptions considered satisfactory by CDE for most decisions about the suitability of a school campus site near a pipeline. However, there are cases where the result could be unsatisfactory or marginal for the simplified methods of Stage 1 and Stage 2. In these cases, provision is made for a Stage 3 level of analysis. Stage 3, by definition, involves a more detailed analysis of school site-specific or pipe segment-specific factors than evaluated in a Stage 1 or Stage 2 analysis.

A LEA may elect to bypass a preceding analysis level and go directly to the next more detailed level. Each of these analyses is described in the following subsections.

If a risk analysis fails to meet the CDE IR criterion, the LEA has the option to request from CDE an exemption from the Title 5 standard. According to Title 5, Section 14010(u), CDE may grant exemptions if the LEA can demonstrate that mitigation of specific circumstances overrides a standard without compromising a safe and a supportive school environment. CDE would determine this on a case-by-case basis.



[a] The Phase I Environmental Assessment required in the CDE site evaluation process is a good potential source of some of the school site and pipeline information required for a risk analysis. Other such documents include Geohazard Studies or California Environmental Quality Act (CEQA) documents.

Figure 4-1. Overall Risk Analysis Process Flow

4.4 Stage 1 - Risk Screening Analysis

In some situations, analysis has revealed certain combinations of pipe size, pressure, product, and distance from the school campus property line will result in an IR value that will meet the CDE IR criterion. As more pipeline risk analyses are completed under the CDE requirements, the number of these cases will reveal themselves. For all such cases, given the parameters of the specific case, if certain conditions are met, no further analysis will be required to establish the level of IR that the pipeline and campus site combination of parameters will present.

The risk analysis can be completed by comparing the case conditions with conditions specified below for natural gas, and liquids product (crude oil and refined products) lines.

Some gas and liquid pipeline-specific conditions, for which a Stage 1 assessment applies, for a single pipeline, include:

For natural gas lines,

- A single pipeline lies within the 1,500-ft zone with a segment length within the zone of no more than 1000 ft.
- The product is natural gas at a pressure of 400 psig or less.
- The line is 24 inches or less in diameter.
- The pipeline is 600 ft or more from the property line (or boundary between the usable portion of the school site and unusable portion facing the pipeline), although within the 1,500-ft criterion.
- Most of the line lies downwind from the campus site and prevailing winds are away from the site.
- The line is approximately parallel to the nearest campus property line.
- The base failure frequency for the gas pipeline system has a value of 1.2E-04 releases/mile-year or less. (Note: It is the convention throughout this Protocol to use spreadsheet scientific notation because of its common use and convenience in word processing documents. 1.2E-04 corresponds to the conventional scientific notation of 1.2×10^{-4}. Both represent the decimal 0.00012.)
- The risk analyst, after reasonable investigation, has no knowledge of significant pipeline regulatory violations by the operator over the last five years, or unresolved or pending regulatory action against the operator.

For petroleum product lines,

- A single pipeline lies within the 1,500-ft zone with a segment length within the zone of no more than 1000 ft.
- The line is 16 inches or less in diameter.
- The product does not have a flammability limit below 1.05 % at atmospheric pressure, and is crude oil or refined products such as gasoline, jet fuel, heating oil, or diesel fuel, and not natural gas liquids (NGL), liquefied gases (such as ethylene or LPG), or similar highly volatile liquids.

- The line is 600 ft or more from the property line (or boundary between the usable portion of the school site and unusable portion facing the pipeline), although within the 1,500-ft criterion.
- The terrain is relatively flat and there is no significant potential for drainage toward the school campus site that would result in product within 600 ft of: 1) the nearest property line or on the campus property, or 2) the boundary between the of the net usable portion of the property and the unusable portion of the property facing the pipeline. The latter would occur in cases where there might be substantial unusable acreage between the property line near the pipeline and where development or activities would actually occur on the property.
- Most of the line is downwind from the campus site and prevailing winds are away from the site.
- The line is approximately parallel to the nearest campus property line.
- The base failure frequency for the liquid pipeline system has a value of 1.3E-03 releases/mile-year or less.
- The risk analyst, after reasonable investigation, has no knowledge of significant pipeline regulatory violations by the operator over the last five years, or unresolved or pending regulatory action against the operator.

Table 4-1 summarizes the key boundary conditions for screening when only a single pipeline within the 1,500-ft zone must be evaluated. All of the criteria specified in Table 4-1 must be met to satisfy the requirements for using Stage 1. If multiple pipelines lie within the 1500 ft zone, then a Stage 2 analysis is required.

Table 4-1. Boundary Conditions for Stage 1 Screening Risk Assessment

Natural Gas Pipeline	Variable Value
Maximum segment length, ft	1000
Minimum distance from pipeline to campus site property line, ft	600
Maximum pipe diameter, inches	20
Maximum pressure, psig	400
Maximum failure rate (F0), releases/mi-yr	1.2E-04 (i.e., 0.00012)
Petroleum Liquid Pipelines	
Maximum segment length, ft	1000
Minimum distance from liquid pool to campus site property line, ft	600
Maximum circular pool diameter, ft	200
Maximum rectangular pool dimensions, ft - Length - Width	 5280 10
Maximum failure rate (F0), releases/mi-yr	1.3E-03 (i.e., 0.0013)

Under the above conditions, the default values of IR, for purposes of the CDE report form, (Section 5) may be taken to be "1.0E-06 or less."

Section 4.7.6 discusses risk analysis requirements for high volume water pipelines.

4.5 Stage 2 – Probabilistic Analysis

The Stage 2 analysis uses a standard calculation Protocol and default data contained within this document (or other similar data) to arrive at a numerical estimate for IR. A numerical example is presented in this section as an illustration of the methodology.

4.5.1 Technical Basis for Probability Calculations

The overall methodology is based on established techniques well known and documented in the field of loss prevention. The foundation of the risk estimate is an event tree analysis. The event tree is a standard analytical structure for examining the consequences of a base event, in this case, a pipeline failure and product release. The calculation begins with a base probability for pipeline failure, followed by calculations using conditional probabilities for ensuing events up through the impact on a hypothetical individual at a specified school campus site location. The probability of that impact is the mathematical product of multiple probabilities along the event chains for various possible hazard scenarios, included in the Protocol. An event tree for a pipeline failure and ensuing events is shown in Figure 4-2.

A pipeline failure can result in a release with an un-ignited dispersion of gas or liquid vapors, or a fire or an explosion that harms persons within an impact zone defined by harmful intensity levels of the physical effects. These impact levels will vary with the specific hazardous event at various locations and distances from the pipeline on the school campus site. Estimating the risk consists of several determinations:

- The physical effect of fire or explosion at the defined receptor location; for estimating the IR, for comparison with the CDE IRC, this location is the center of the campus site property line nearest the pipeline, or the boundary between the net usable portion of the property and the unusable portion facing the pipeline;
- The probability of exposure to those effects (i.e., the probability that an individual would be at the campus site at the time of a release and fire or explosion); and
- The probability that such exposure would result in one fatality.

The probability of the final event is the mathematical product of the individual event probabilities, as illustrated in the event tree. Calculations follow from the basic mathematics of event tree probabilities, as discussed further in the following commentary.

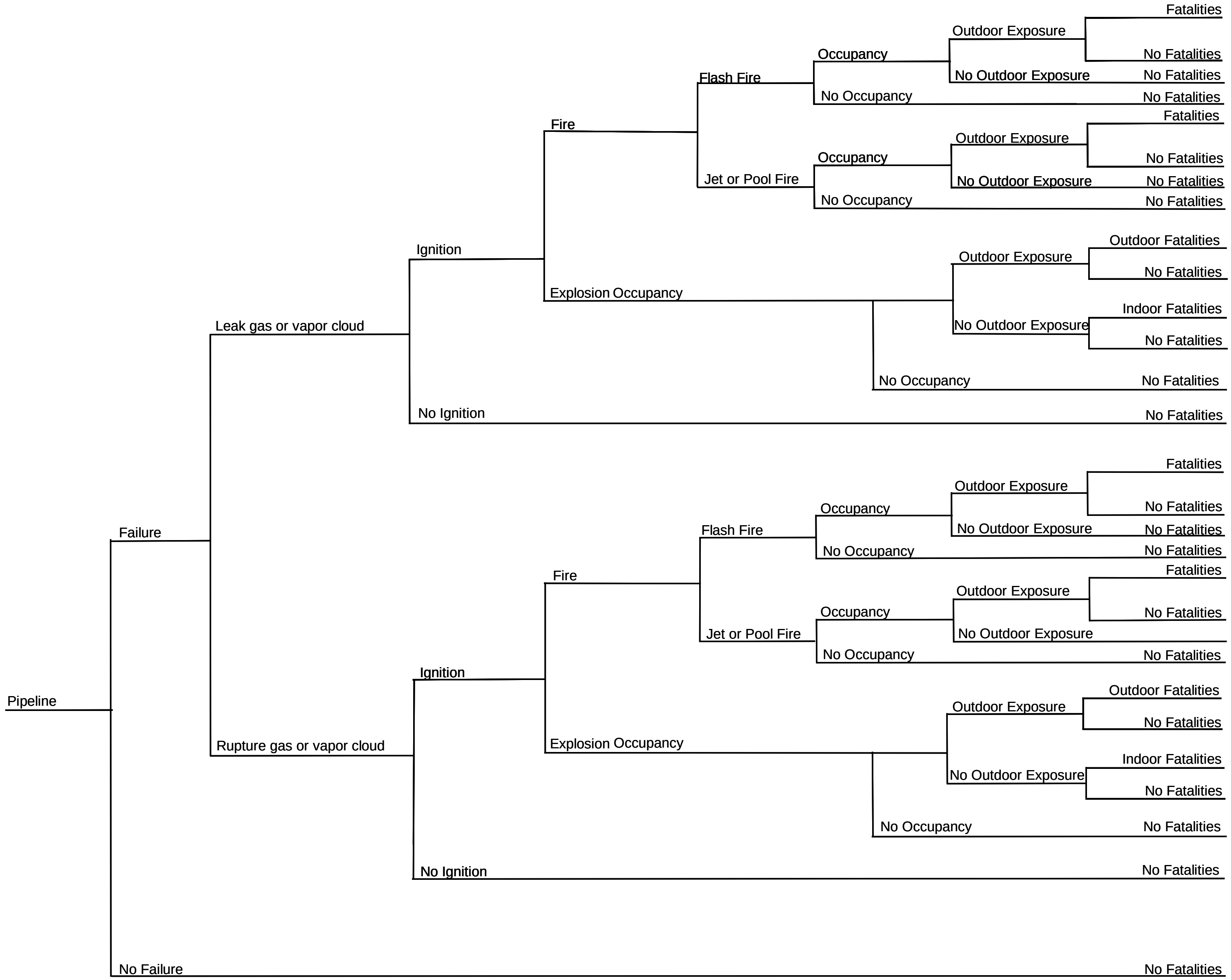


Figure 4-2. Event Tree Showing Example Probability Calculation for Pipeline Failure Consequences

4.5.2 Estimating the Individual Risk

The Individual Risk (IR) for a specified hazard is the probability of fatality for an individual exposed to the physical impact of that hazard, for a specified location, within a specified span of time. Standard practice in Quantitative Probabilistic Risk Analysis for accidental chemical release impacts is to examine annual probabilities. The probability criterion is based on the probability of an event within any given year span of time.

For hazards associated with accidental releases of product from pipelines, the IR for an individual in the vicinity of the pipeline is usually based on exposure to a flash fire, jet fire (or pool fire for liquid releases), or explosion. These hazards are the basis for the IR determined in the Protocol.

Individual exposure depends on the hazard impact distance and the distance between the hazard source and the individual receptor location. This is illustrated later Section 4.5.2.2.

The concept of IR from a point hazard source is well established in hazardous materials risk analysis associated with studies for siting both fixed facilities and transportation (CCPS 1989, 1995). For an individual at a specified location subject to a hazard source, the IR is generally defined by the following equation (CCPS 1989):

$$IR(i,X) = PC(i,X) \times PF(i,X) \qquad \text{(Eqn. 4-1)}$$

Where,

IR(i,x) = the individual risk at a defined location, i, for a defined hazard, X
PC(i,X) = the probability for an individual's exposure to hazard X's impact at location, i; and
PF(i,X) = the probability of fatality, at location i, from the impact of hazard X.

Using a rupture jet fire (RJF) as an example, the IR for a rupture jet fire, IR(RJF) is:

$$IR(i,RJF) = PC(i,RJF) \times PF(i,RJF) \qquad \text{(Eqn. 4-2)}$$

Where,

PC(i,RJF) = the probability of receptor exposure to a RJF; and
PF(i,RJF) = the probability of a fatality upon exposure.

This Protocol considers six distinct types of release hazards as "Protocol Basis Scenarios." They are as follows: leak jet (or pool for liquids) fire (LJF); rupture jet (or pool) fire

(RJF); leak flash fire (LFF); rupture flash fire (RFF); leak explosion (LEX); and rupture explosion (REX).

For a given length of pipeline within 1500 ft of a school campus property line, each of these hazards has a unique length of pipe from which the impacts of the hazard could reach a receptor. Outside of this length the impacts could not reach the receptor. The segment length for which a hazard X can have an impact is the length XSEG. Determination of the hazard impact distance and the XSEG is explained respectively in Sections 4.5.2.1 and 4.5.2.2.

After the IR for the individual hazards is determined, the total IR (TIR) for all hazards is determined by applying the form of Equation 4-3 to the individual hazards. Using the acronyms previously assigned, Equation 4-3 can be written as:

$$IR = IR(LJF) + IR(RJF) + IR(LFF) + IR(RFF) + IR(LEX) + IR(REX) \qquad \text{(Eqn. 4-3)}$$

Details of this method are discussed in the remainder of Section 4. Some of the overall simplifying assumptions in this method as applied in the Protocol are:

- All hazards originate at a point location along the pipeline segment of concern, within their respective XSEGs;
- The wind distribution is uniform;
- A single wind speed and atmospheric stability class are used;
- No mitigation factors are considered;
- Ignition sources are uniformly distributed (the probability of ignition does not depend on release directions); and
- Consequence effects can be treated discretely. The impact level from a particular increment is constant, and the effect in a defined impact zone is constant.

The Protocol provides for two types of calculations involving the IR:

- Estimating the IR at a specific distance from the hazard source in a pipeline segment; and
- Estimating the distance corresponding to a specified level of IR.

The fundamental approach in the Protocol is the former, as described in detail in the remainder of this Section. The Protocol also describes the latter, which can be done through the basic process by iterating on distance as described briefly later in this Section.

The steps of an analysis, in sequence, determine the:

1. Hazard impact distance. *
2. XSEG length for each of the three hazard types based on the distance between the receptor and the pipeline hazard source, and the hazard impact distance.
3. Maximum mortality impact from the closest approach of the pipeline to the receptor.
4. Average mortality at the receptor for each XSEG.
5. Base adjusted failure probability for the pipeline.
6. Base probability for each XSEG.
7. Conditional probability factor for each event scenario.
8. Conditional probability of individual exposure.
9. IR at the specified locations.

These steps are briefly explained followed by a numerical example. A more detailed explanation is also available in Volume 2.

4.5.2.1 Hazard Impact Distance

Appropriate hazard consequence modeling of product releases is the basis for estimating the hazard impact distances.

The scenarios apply for each of the hazard categories previously stated, i.e., flash fires, jet fires (pool fires for liquid releases), and unconfined gas or vapor explosions. The Protocol uses several Protocol Basis Scenarios for which modeling has been applied over a span of combinations of typical pipeline conditions and setting conditions.

Based on the specific parameters of a given situation, the impacts can be estimated using figures and tables of release impacts provided in Section 4.9 of this Protocol. Data needed for the uses of this part of the evaluation include the following:

1. Product transported by the pipeline;
2. Pipeline diameter;
3. Pipeline operating pressure;
4. Minimum distance between the pipeline and the property line (or boundary between the unusable portion and usable portion of a site, which may apply to some sites);

* Some use other terminology for impact distance such as “impact radius”, “hazard footprint length”, etc.

5. Orientation of the pipeline to the property line (i.e., parallel, perpendicular, at an angle, etc.);
6. Length of property line exposed to pipe length of concern, the length of the pipeline segment that lies within 1,500 feet of the school property line; and
7. The receptor location distance, which has been defined by CDE as the center of the property line nearest to the pipeline (or boundary between the unusable portion and usable portion of a site, which may apply to some sites).

Table 4-2 illustrates how some of these data will be compiled.

Table 4-2. Data Input Requirements with Example Values Shown

Description	Variable	Example Value	Data Source
Pipeline diameter, inches	D	30	Phase I study or other information.
Pipeline pressure, psig	P	400	"
Exposed property line length, ft	LPL	500	Campus site location maps.
Receptor location distance nearest hazard source, ft	R0	250	Selected in accordance with the Protocol.
Nearest property line distance, ft	R	250	This would be the same as R0 when the receptor location is on the nearest property line.

4.5.2.2 Individual Hazard Segment Length (XSEG)

The individual hazard "X" segment length (XSEG) is the length of pipe within the segment of concern from which a product release would result in a flash fire, jet or pool fire, or explosion, the impacts of which could reach the receptor with potential for fatality at a level of at least 1% mortality (fatality probability of 0.01). The 1% level is believed to be a reasonable estimate of the boundary of serious harm. It is, by definition, for whole number estimates of mortality, the demarcation between threat (1% mortality or higher) and no-threat (0% mortality). It can be interpreted as conservative relative to other low values that could be used. For example, compared with using a 5% or 10% lower limit as a tolerance level for defining a hazard boundary zone, the 1% level results in a greater XSEG length than these other values and hence a larger estimated probability of failure.

The XSEG length is determined from the longest impact distance that can reach from the pipeline to the receptor and have a 1.0% mortality impact. This distance is determined for each hazard type. To determine the XSEG length one must first determine the distance corresponding to a 1.0% mortality impact. Once known, the XSEG length is determined based on the relationship shown in Figure 4-3, and the following equation:

$$XSEG = 2\,(RX(1\%)^2 - R0^2)^{0.5} \qquad \text{(Eqn. 4-4)}$$

Where,

RX(1%) = the distance from the hazard source to the receptor location for a 1% mortality impact (i.e., 0.01 fatality probability impact).

R0 = the distance from the hazard source to the receptor location.

The hazard length is calculated for each of the Protocol Basis Scenarios defined earlier.

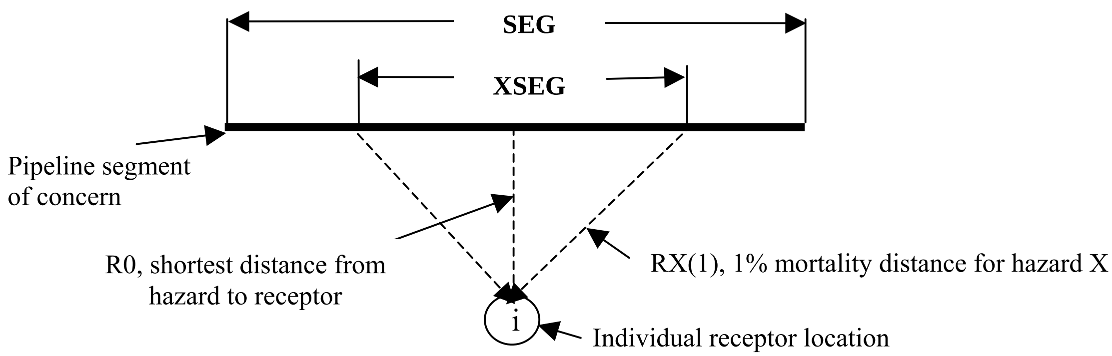


Figure 4-3. Basis for XSEG Determination

4.5.2.3 Maximum and Average Mortality and Fatality Probability

The mortality (the fatality probability expressed as a percentage; 100% mortality equals a probability of 1.0) depends on the distance between the hazard source and severity of the impact at the receptor location. Mortality data from the technical literature were used to estimate the mortality from fire heat radiation and explosion overpressures. For flash fires, a simplifying assumption is that the mortality is 100% within the zone bounded by the lower flammability limit (LFL) concentration (defined in Volume 2, Section 2.4.1). This is conservative as the survivability in this zone depends on the specific concentration profile within a specific cloud of gas or vapor, the exact pattern of the flame front, the location of an individual relative to the flame front as it passes through the cloud and other factors unique to each situation. There have been fires in which the mortality was less than 100%.

Figures 4-4 and 4-5 present mortality data. Figure 4-4 is for heat radiation from fires based on the mortality from exposure to fire heat radiation, based on data in a Gas Research Institute Report on natural gas fires (GRI 2000). Figure 4-5 is for overpressures from explosions from the technical literature of the American Institute of Chemical Engineers, Center for Chemical Process Safety (CCPS 1996). The overpressure data is for indoor exposure and is conservative if applied for outdoor exposure.

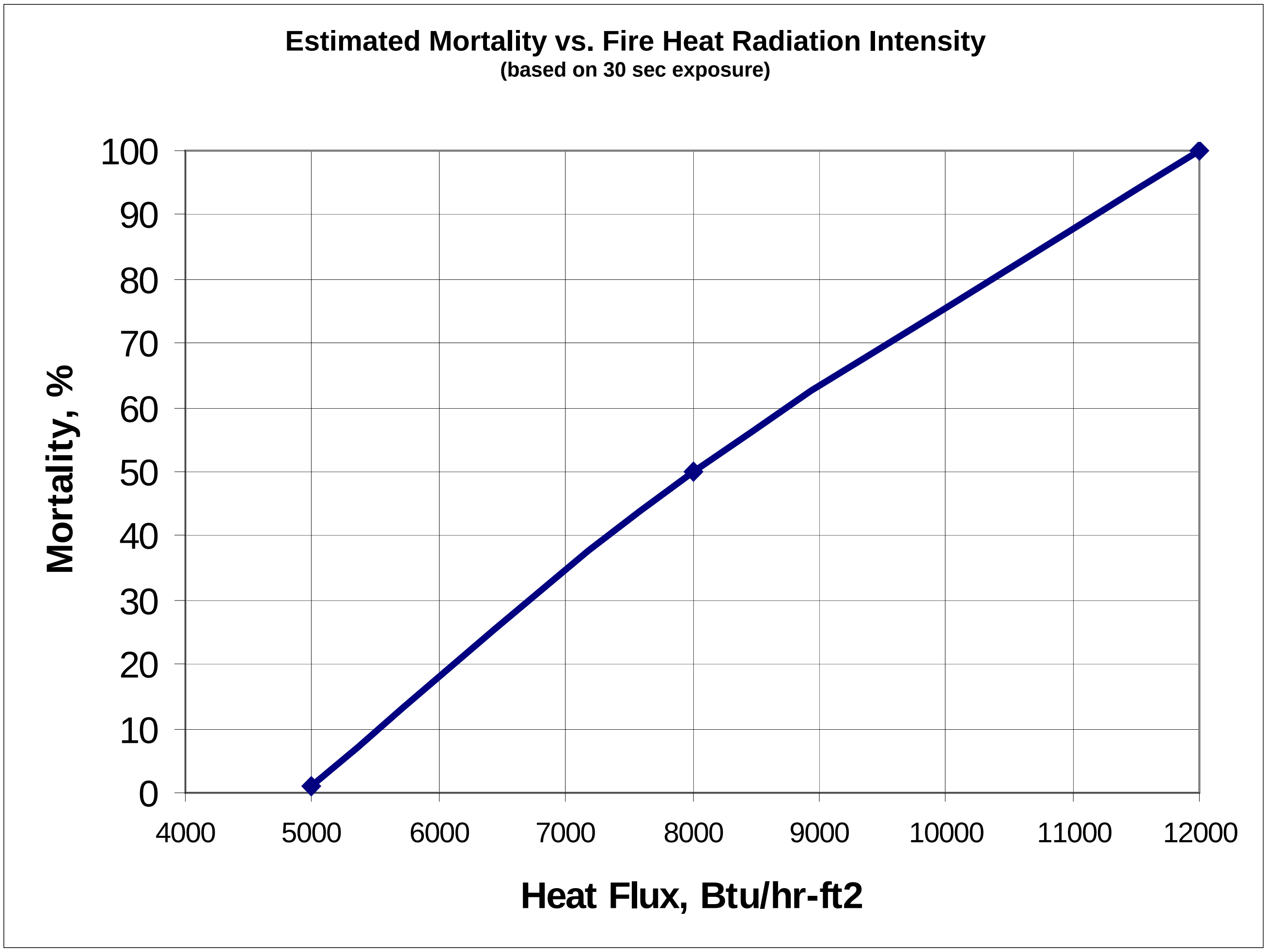
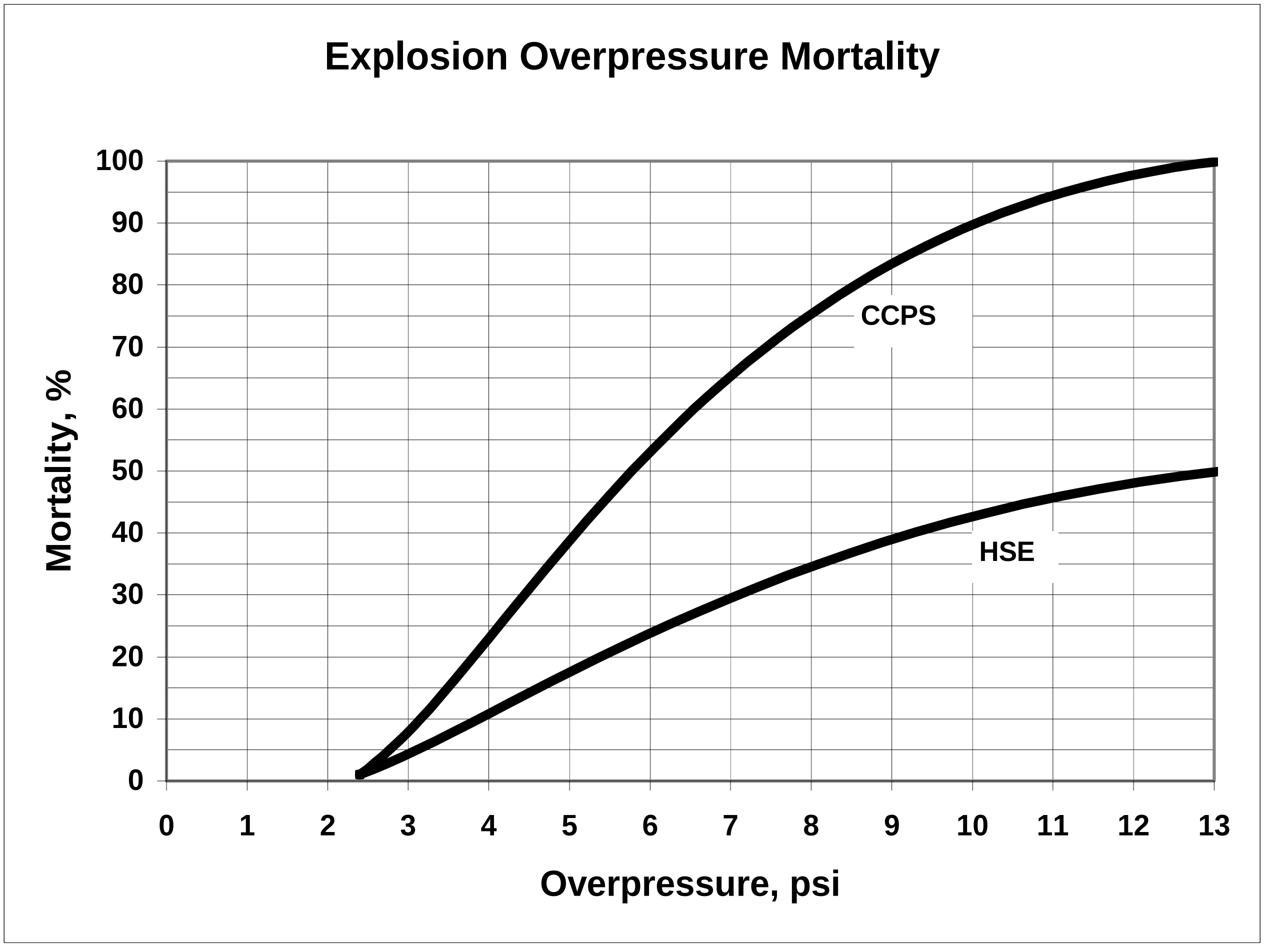


Figure 4-4. Estimated Mortality from Fire Heat Radiation



Note: The CCPS curve strictly applies to persons inside of buildings. The Health and Safety Executive (HSE) of the U.K. curve applies to persons outdoors. The CCPS curve is suggested as a conservative basis for estimating in an initial Stage 2 analysis.

Figure 4-5. Estimated Mortality from Explosion Overpressure

An equation was fitted to the heat radiation mortality curve was fitted to tabular data given in a CCPS book (CCPS 1994). The equation is:

$$M(\%) = (-5.55E\text{-}07)I_{th}^2 + 0.0236\ I_{th} - 103 \qquad \text{(Eqn. 4-5)}$$

Where,

M (%) = mortality as a percentage, and

I_{th} = heat radiation intensity in Btu/hr-ft^2.

The explosion mortality is based on the CCPS data in the reference cited above. The data were fit to the following equation:

$$M(\%) = -0.7817(OP)^2 + 21.354(OP) - 44.99 \qquad \text{(Eqn. 4-6)}$$

Where:

M(%) = mortality as a percentage; and

OP = the explosion overpressure in psi.

Liquid impacts analysis uses the same mortality curves for thermal radiation and overpressure exposure.

These equations can also be written in terms of distance from the hazard source by substituting for I_{th} and P, respectively.

The average mortality provides the probability of fatality (PF(X)) used in the final IR calculations. It is calculated as the arithmetic average of the maximum mortality, calculated above, and the 1% mortality. It represents the average over each XSEG.

The mortality data are also used in estimating the length of XSEG.

4.5.2.4 Probability of Hazard Impacts at Specified Receptor Location

Once the average mortality has been determined for a given XSEG, the next step is to determine the probability of impact from a failure of that pipeline segment. This consists of determining the probability of a product release from that segment, and the probability of the given hazard impact.

Base Product Release Frequency and Probability

The base probability value is computed from a base frequency value for pipeline failure and a product release, F0. The annual frequency of pipeline failure and product releases is based on historical data from the OPS Gas Pipeline Incident Database or Hazardous Liquid Pipeline

Accident Database (available at www.phmsa.dot.gov). Data for use in the Protocol is presented in Table 4-3. These failure rates are based on historical data for significant releases specific to pipelines in California. See Volume 2 for details on derivation.

Table 4-3. Normalized Pipeline Average Failure and Release Frequencies (F0) for California Pipelines (1984-2001 Period)

Pipeline Product	Pipeline Service Type[a]	F0, Number of Releases/mile-year	
Natural Gas	Transmission Line	1.2E-04	(0.00012)
Natural Gas	Gathering Line	2.1E-04	(0.00021)
Natural Gas	Distribution Main Line	4.6E-05	(0.000046)
Hazardous Liquids – All Commodity Types	Transmission Line	1.8E-03	(0.0018)
Crude Oil	Transmission Line	2.3E-03	(0.0023)
Refined Product	Transmission Line	1.3E-03	(0.0013)

Source: OPS Gas Pipeline Incident and Hazardous Liquid Pipeline Accident Databases, 2000.
[a] As defined in OPS regulations.

The values in the table compare with values of between 5.0E-04 and 1.5E-03 for all pipelines presented in the "Brown Book", and suggested for estimating pipeline failure rates for frequency calculations in emergency planning (FEMA 1989).

Base Release Probability

The probability of a pipeline failure resulting in the release of product with a specified hazard begins with calculation of base probability from the base release frequency (F0), using a Poisson probability estimate of "one or more" releases in a given year of pipeline operation. A mathematical derivation leads to the following equation:

$$P0 = 1 - e^{(-F0 \times t)} \qquad \text{(Eqn. 4-7)}$$

Where,

F0 = the average release frequency for the pipeline in releases/mi-year; and

t = the time period for which the probability is sought; all probabilities in this Protocol are based on one year, so t =1.

For the small frequency numbers encountered for pipeline failure rates, the equation yields an annual probability value that is numerically equal to the annual frequency as illustrated below:

P0 = 1 – exp (-F0 × t), where t is taken to be a probability time basis of 1 year

P0 = 1 – exp [(-1.2E-04) × (1)]

P0 = 1.2E-04 (or 0.00012, expressed as a decimal)

This probability is adjusted as needed to account for special site conditions that suggest the average failure rate should be adjusted. Guidance on this point is provided in Volume 2 of the Protocol. This is then followed by the application of various conditional probabilities associated with specific hazard scenarios that derive from the initial product release as was illustrated in the event tree of Figure 4-2, shown earlier.

Adjusted Base Probability

The base probability (P0) is multiplied by a probability adjustment factor (PAF) to yield the Adjusted Base Probability (PA):

$$PA = P0 \times PAF \qquad \text{(Eqn. 4-8)}$$

Failure frequencies can increase or decrease depending on a number of conditions, such as the quality of the maintenance program, corrosive soil conditions at one location compared with another, and types of third party activity likely to be encountered near a specific segment. These variations contribute to the inherent uncertainty in estimated risk values. The Probability Adjustment Factor (PAF) allows for the modification of the base value by expert judgment, based on knowledge of specific segment conditions and changes in pipeline management over time.

The probability adjustment factor is a convenient way to account for special circumstances surrounding seismic effects and other "earth movement" phenomena unique to certain locations in California.

The California data from the OPS database already account for seismic and other earth movements as causes for reportable incidents in the data compilation period. However, because of the potential damage to pipelines from earthquakes may vary significantly throughout the State, the PAF provides a mechanism for incorporating local seismic event-induced probability considerations into the analysis if deemed necessary. Whether further geotechnical review or other qualified geotechnical/pipeline specialists (e.g., CA certified, registered) are required for this issue will be at the discretion of the risk analyst. If the threat to a pipeline from a local geologic condition is deemed significant, appropriately qualified professionals would then need to determine the amount of upwards adjustment to the pipeline failure and product release base probability that is already provided in the Protocol.

A potential trigger for additional geotechnical review and possible upward probability adjustment is if the pipeline segment within 1,500 feet of the site is located within identified seismic hazard areas. Maps of these areas are prepared by the California Geological Survey and delineate areas subject to a high potential for significant ground displacement by faulting, liquefaction, landslides and strong ground motion. Other sources of information regarding a local seismic threat could include prior geologic/geotechnical studies independently completed for the school site or nearby locations, pipeline owner/operator data, and/or city/county general plans. Additional discussion on seismic issues and information resources are provided in Volume 2, Section 5.

4.5.2.5 Base Probability for Each Hazard Segment Length (XSEG)

Only the length of pipe defined by each XSEG length is capable of yielding an IR impact at the receptor location for the corresponding hazard, X. Product releases outside the XSEG do not threaten the receptor with a fatality, since the XSEG lengths were defined by the limits of such impacts reaching the receptor. The PA is converted to PA(X) for each hazard scenario as follows:

$$PA(X) = (XSEG/5{,}280) \times PA \qquad \text{(Eqn. 4-9)}$$

XSEG/5280 is merely the ratio of the given hazard segment length, XSEG in feet to the number of feet in a mile (5,280).

4.5.2.6 Conditional Probability for Each Hazard Impact

The conditional probabilities for the various hazard impacts, PCI(X), are determined by the following equations:

Leak Jet or Pool Fire: $PCI(LJF) = PC(L) \times PC(LIG) \times PC(FIG) \times PC(JF)$ (Eqn. 4-10)

Rupture Jet or Pool Fire: $PCI(RJF) = PC(R) \times PC(RIG) \times PC(FIG) \times PC(JF)$ (Eqn. 4-11)

Leak Flash Fire: $PCI(LFF) = PC(L) \times PC(LIG) \times PC(FIG) \times PC(FF)$ (Eqn. 4-12)

Rupture Flash Fire: $PCI(RFF) = PC(R) \times PC(RIG) \times PC(FIG) \times PC(FF)$ (Eqn. 4-13)

Leak Explosion: $PCI(LEX) = PC(L) \times PC(LIG) \times PC(EIG)$ (Eqn. 4-14)

Rupture Explosion: $PCI(REX) = PC(R) \times PC(RIG) \times PC(EIG)$ (Eqn. 4-15)

Protocol default conditional probabilities for use in these equations are listed in Table 4-4.

Table 4-4. Conditional Probabilities

Conditional Probability of Occurrence Associated with a Product Release	Variable Designation	Gas Pipeline Value	Crude Oil Pipeline Value	Petroleum Product Pipeline Value
Probability of leak	PC(L)	0.8	0.8	0.8
Probability of rupture	PC(R)	0.2	0.2	0.2
Probability of ignition from leak	PC(LIG)	0.3	0.09	0.09 (gasoline) 0.03 (other liquids)
Probability of ignition from rupture	PC(RIG)	0.45	0.03	0.09 (gasoline) 0.03 (other liquids)
Probability of fire from ignition	PC(FIG)	0.99	0.95	0.95
Probability of explosion from ignition	PC(EIG)	0.01	0.05	0.05
Probability of flash fire from ignition	PC(FF)	0.01	0.05	0.05
Probability of jet fire (gas pipelines) or pool fire (liquid pipelines)	PC(JF)	0.98	0.95	0.95
Probability of occupancy	PC(OCC)	0.16	0.16	0.16
Probability of outdoor exposure	PC(OUT)	0.25	0.25	0.25

Source: See Volume 2.

[a] User may substitute other values for default values, if desired, along with supporting documentation. Data sources do not relate values to release orientation for gas releases, so by default, the same values are used for both.

4.5.2.7 Conditional Probability of Individual Exposure

An individual can be affected only if that person is present at the impact location when an incident occurs. The probability of exposure is given as:

$$PC(EXPO) = PC(OCC) \times P(OUT) \qquad \text{(Eqn. 4-16)}$$

Where,

PC(OCC) = the probability of occupancy at the campus in a given year;

P(OUT) = the probability of being outdoors during occupancy in a given year.

This is estimated for an individual campus for the average individual. Default values for this Protocol are based on occupancy for 180 days per year, 8 hours per day to yield:

PC(OCC) = 180 days/year x 8 hours/day / 8760 hours/year = 0.16

PC(OUT) is assumed to be 2 hours per day so the probability of being outdoors during an 8-hour day is 2/8 = 0.25. The default PC(EXPO) = 0.16 x 0.25 = 0.04.

4.5.2.8 Hazard Conditional Probability and IR Calculations

The final step in the analysis is calculation of the individual hazard conditional probabilities and PC(X), the hazard impacts and the fatality probabilities PF(X), and the individual hazard Individual Risks IR(X), and the Total IR.

The individual hazard conditional probabilities are given by the following equations:

Leak Jet or Pool Fire: PC(LJF) = PA(LJF) x PCI(LJF) x PC(EXPO) (Eqn. 4-17)

Rupture Jet or Pool Fire: PC(RJF) = PA(RJF) x PCI(RJF) x PC(EXPO) (Eqn. 4-18)

Leak Flash Fire: PC(LFF) = PA(LFF) x PCI(LFF) x PC(EXPO) (Eqn. 4-19)

Rupture Flash Fire: PC(RFF) = PA(RFF) x PCI(RFF) x PF(EXPO) (Eqn. 4-20)

Leak Explosion: PC(LEX) = PA(LEX) x PCI(LEX) x PC(EXPO) (Eqn. 4-21)

Rupture Explosion: PC(REX) = PA(REX) x PCI(REX) x PC(EXPO) (Eqn. 4-22)

The individual hazard IRs are given by the following equations:

Leak Jet or Pool Fire IR: IR(LJF) = PC(LJF) x PF(LJF) (Eqn. 4-23)

Rupture Jet or Pool Fire IR: IR(RJF) = PC(RJF) x PF(RJF) (Eqn. 4-24)

Leak Flash Fire IR: IR(LFF) = PA(LFF) x PCI(LFF) (Eqn. 4-25)

Rupture Flash Fire IR: IR(RFF) = PA(RFF) x PCI(RFF) (Eqn. 4-26)

Leak Explosion IR: IR(LEX) = PA(LEX) x PCI(LEX) (Eqn. 4-27)

Rupture Explosion IR: IR(REX) = PA(REX) x PCI(REX) (Eqn. 4-28)

The total IR is the sum of the contributions for the IR for each hazard.

TIR = IR(LJF) + IR(RJF) + IR(LFF) + IR(RFF) + IR(LEX) + IR(REX) (Egn. 4-29)

This calculated value is compared to the CDE IRC of 1.0E-06. If TIR > IRC, TIR is “significant”; otherwise it is “insignificant”.

The foregoing steps in the estimating the IR can be summarized as:

Step 1: Estimate the hazard impact, maximum distance for each Protocol Basis Scenario.

Step 2: Estimate the hazard segment length, XSEG, for each hazard scenario.

Step 3: Estimate the base release frequency (F0), the base annual release probability per mile of pipeline (P0), and the adjusted base probability PA using the probability adjustment factor, PAF. Determine the base annual probability for each hazard scenario for the estimated hazard segment length.

Step 4: Estimate the conditional probability of impact for each hazard scenario, PCI(X).

Step 5: Estimate the conditional probability of individual exposure, PC(EXPO).

Step 6: Estimate the hazard impact severity at the receptor location, the mortality, and fatality probability if exposed to the impact for each hazard scenario, PF(X).

Step 7: Estimate the hazard conditional probability at the receptor location PC(X).

Step 8. Estimate the individual risk contribution IR(X) of each hazard (X) scenario.

Step 9: Estimate the total individual risk (TIR).

The Total Individual Risk requires a repeat of the above steps of each of the other five hazard scenarios and IR(X). The TIR is then computed. This value is included in a risk analysis report to CDE as discussed in Section 5.

The following numerical example illustrates the process for a natural gas pipeline.

4.5.3 Numerical Example for a Natural Gas Pipeline

This section presents a numerical example for applying the risk estimation methodology to a natural gas pipeline. The same general method applies for a liquid pipeline with appropriate changes in the specific data used in arriving at the final estimate, as described later in this document.

Consider the following example:

A 30-inch diameter natural gas transmission pipeline with an operating pressure of 400 psig is located within the 1,500-foot applicability zone for a proposed school campus site. Based on the site maps, the pipeline is estimated to have a segment length of 0.655 mile within the 1,500-ft zone of interest. The distance between the pipeline and nearest school campus site property line is 250 ft. The site is considered relatively open with little confinement potential for a gas cloud explosion. Estimate the IR at the center of property line for comparison with the IRC.

Using the steps listed in the preceding section the computation for the rupture jet fire scenario

Step 1: Estimate the hazard impact, maximum distance for each Protocol Basis Scenario.

The hazard impact maximum distance is defined as that distance, RX(1) for which a hazardous impact with a mortality of 1% can just reach the receptor location from the pipeline. This distance is used to estimate the XSEG length that corresponds to the type of hazard scenario. In this example, a rupture jet fire is analyzed. Other scenarios are handled similarly. The XSEG is required to estimate the probability of the scenario, as in Step 2, below.

For a natural gas rupture jet fire, the estimated heat radiation impact distance for a 30-inch, 400 psig pipeline is shown in Figure 4-13. The bottom line in the figure corresponds to a heat radiation impact of 5000 Btu/hr-ft^2 or 1% mortality. (The top line corresponds to 12000 Btu/hr-ft^2 or 100% mortality.) Using Figure 4-13 for a pressure of 400 psig, for the 5000 Btu/hr-ft^2 or 1% mortality, the corresponding impact distance, RRJF (1) is 640 ft from the pipeline.

Step 2: Estimate the hazard segment length, XSEG, for each hazard scenario.

The hazard segment length XSEG for hazard X is given by Equation 4-3:

$$XSEG = 2 \text{ x } (RX(1)^2 – R0^2)^{0.5}$$

For this case,

$$XSEG = XSEG(RJF) = 2 \text{ x } (RRJF(1)^2 - 250^2)^{0.5} = (640^2 - 250^2)^{0.5} = 1178 \text{ ft.}$$

The calculations for the other scenarios are handled similarly, except for flash fires. In that case the impact distance for all pipeline sizes are taken from a single figure, Figure 4-16 because the mortality level is assumed to be invariant within a flash fire zone.

The hazard length, XSEG(RJF), is used to estimate the base annual probability of a rupture jet fire scenario, shown next.

Step 3: Estimate the base release frequency (F0), the base annual release probability per mile of pipeline (P0), and the adjusted base probability PA using the probability adjustment factor, PAF. Determine the base annual probability for each hazard scenario for the estimated hazard segment length.

For a gas transmission line the base release frequency, F0, is found in Table 4-3. For reasons explained in the text, this can be taken as the annual probability of an accidental release of product from the pipeline, P0. It is the average annual probability of release per mile of pipeline. PAF = 1.0 for this example, and is used unless there is reason for another value as explained in the PAF discussion.

F0 = 1.2E-04 incidents / mile-year

Using Equation 4-7, it can be shown that it can be shown that, for this value of F0, the numerical value of P0 equals the numerical value of F0. The probability of a pipeline reportable accidental release in any mile, in a given year is,

P0 = 1.2E-04

The adjusted base probability is obtained from Equation 4-8,

PA = P0 x PAF

With a probability adjustment factor of 1.0, assumed for this case, the adjusted base probability remains as above at 1.2E-04.

Once the individual hazard segment lengths have been estimated, the base probability of each hazard scenario is determined by Equation 4-9,

PA(X) = (XSEG/5,280) x PA

For this example,

PA(RJF) = (XSEG(RJF)/5280) x PA = (1178/5280) x 1.2E-04

= (0.223) x (1.2E-04) = 2.7E-05.

The individual base probabilities for the other hazard scenarios are handled similarly.

Step 4: Estimate the conditional probability of impact for each hazard scenario. Next the conditional probability associated with each hazard scenario is applied. This probability is given by the equations in Section 4.5.2.6. For the example, equation 4-11 for a natural gas jet fire gives the conditional probability for a rupture jet fire.

PCI(RJF) = PC(R) x PC(RIG) x PC(FIG) x PC(JF)

Using the appropriate values in Table 4-4 yields,

PCI(RJF) = 0.2 x 0.45 x .0.99 x 0.98 = 0.09

This is the conditional probability that a pipeline release will be a rupture, jet fire scenario. It says that 20% of the time a pipeline release will be from a full diameter rupture, that 45% of the time it would ignite, that 99% of the time it would result in a fire rather than an explosion, and that 98% of the time the fire would be a jet fire. As explained elsewhere in the protocol, there are only estimates.

Step 5: Estimate the conditional probability of individual exposure. Equation 4-16, Section 4.5.2.7 is used,

PC(EXPO) = PC(OCC) x P(OUT)

For this example, using the default values of Section 4.5.2.7,

PC(EXPO) = 0.16 x 0.25 = 0.04.

Step 6: Estimate the hazard impact severity at the receptor location, the mortality, and fatality probability if exposed to the impact for each hazard scenario, PF(X).

For the example case the estimated fatality probability for the jet fire at the receptor location distance of 250 ft is obtained by referring to two figures. First, the heat radiation intensity at 250 ft is obtained from Figure 4-13 for a 30-inch pipe at 400 psig. For this case the level exceeds 12,000 Btu/hr-ft^2. Then, the estimated mortality for that heat radiation level is determined from the mortality Figure 4-4 for heat radiation from fires. In this case the mortality is 100%. The probability of fatality at the receptor location of 250 ft, from the rupture jet fire, PF(250, RJF) is 1.0 (the mortality divided by 100). The analysis for other scenarios proceeds similarly.

Step 7: Estimate the hazard conditional probability at the receptor location PC(X).

For the example case rupture jet fire, the hazard conditional probability is given by Equation 4-17,

PC(RJF) = PA(RJF) x PCI(RJF) x PC(EXPO) = 4.2E-08

Step 8. Estimate the individual risk contribution IR(X) of each hazard (X) scenario.

Using Equation 4-23, the resulting estimated Individual Risk (IR) for the jet fire hazard is,

IR(RJF) = PC(RJF) x PF(RJF) = 4.2E-08 x 1.0 = 4.2E-08

Step 9: Estimate the total individual risk (TIR).

The Total Individual Risk requires a repeat of the above steps of each of the other five hazard scenarios and IR(X). Then Equation 4-29 is used for the TIR.

The above illustration was for the rupture jet fire scenario. Input data and results for all of the Protocol Basis Scenarios evaluated for this case are summarized in Table 4- 2 through 4-7.

The tables cover:

- Data input;
- Calculations; and
- Results.

Table 4-5. Data Input Table for with Numerical Example Values

Input Data	Value	Units	Data Source
Product	natural gas		Phase I study, pipeline operator, OSFM, other
Diameter	30	inches	Same as above
Pressure	400	psig	Same as above
R0	250	ft	From map or field data measurements
RX(LJF)	33	ft	Invariant based on ALOHA modeling for 1.0-inch hole. May differ if other models are used.
RX(RJF)	640	ft	Sec. 4 figures for impact distances.
RX(LFF)	0	ft	
RX(RFF)	3000	ft	
RX(LEX)	0	ft	ALOHA modeling yielded no GCE explosion overpressures for leaks.
RX(REX)	0	ft	ALOHA modeling yielded no GCE explosion overpressures for ruptures.
XSEG(LJF)	0	ft	Calculated by the method described in Sections 4.5.2.1 and 4.5.2.2
XSEG(RJF)	1178	ft	Same as above
XSEG(LFF)	0	ft	Same as above
XSEG(LJF)	5979	ft	Same as above
XSEG(LEX)	0	ft	Same as above
XSEG(REX)	0	ft	Same as above

Table 4-6. Base and Conditional Probabilities Calculations Including Values for Numerical Example

Base		Leak*		Rupture*		Exposure	
F0	1.2E-04	PC(L)	0.8	PC(R)	0.2	PC(OCC)	0.16
P0	1.2E-04	PC(LIG)	0.3	PC(RIG)	0.45	PC(OUT)	0.25
PAF	1.0	PC(FIG)	0.99	PC(FIG)	0.99		
PA	1.2E-04	PC(JF)	0.98	PC(JF)	0.98		
		PC(FF)	0.01	PC(FF)	0.01		
		PC(EIG)	0.01	PC(EIG)	0.01		
Calculated Values Base Hazard Probabilities		**Leak Impact Probabilities***		**Leak Impact Probabilities***		**Exposure Probability**	
PA(LJF)	0	PCI(LJF)	0.23	PCI(RJF)	0.09	PC(EXPO)	0.04
PA(RJF)	2.7E-05	PCI(LFF)	0.002	PCI(RFF)	0.001		
PA(LFF)	0	PCI(LEX)	0.002	PCI(REX)	0.001		
PA(RFF)	1.4E-04						
PA(LEX)	0						
PA(REX)	0						

*These Protocol default values for Conditional Event and Impact Probabilities always apply, unless values other than these are chosen for use.

Table 4-7. Individual Hazard Probabilities with Values for Numerical Example

Hazard Conditional Probability PC(X)	Base Hazard Probability PA(X)	Conditional Impact Probability Factor PCI(X)	Conditional Exposure Probability PC(EXPO)	PA(X) Value	PCI(X) Value	PC(EXPO) Value	PC(X)
PC(LJF) =	PA(LJF) x	PCI(LJF) x	PC(EXPO) =	0	0.23	4.0E-02	**0**
PC(RJF) =	PA(RJF) x	PCI(RJF) x	PC(EXPO) =	2.7E-05	0.09	4.0E-02	**9.4E-08**
PC(LFF) =	PA(LFF) x	PCI(LFF) x	PC(EXPO) =	0	0.002	4.0E-02	**0**
PC(RFF) =	PA(RFF) x	PCI(RFF) x	PC(EXPO) =	1.4E-04	0.001	4.0E-02	**4.8E-09**
PC(LEX) =	PA(LEX) x	PCI(LEX) x	PC(EXPO) =	0	0.002	4.0E-02	**0**
PC(REX) =	PA(REX) x	PCI(REX) x	PC(EXPO) =	0	0.001	4.0E-02	**0**

Table 4-8. Individual Risk Summary for Numerical Example

IR(X)	Maximum PF(X)		Hazard Conditional Probability PC(X)	IR(X)
IR(LJF) =	0		0	0
IR(RJF) =	1.0		9.4E-08	9.4E-08
IR(LFF) =	0		0	0
IR(RFF) =	1.0		4.8E-09	4.8E-09
IR(LEX) =	0		0	0
IR(REX) =	0		0	0
Example TIR =				**9.9E-08**

4.5.4 Liquid Pipelines

For liquid pipelines, estimating the IR follows the same general approach as for gas pipelines. One unique consideration for liquid lines is that overland flow of liquid can result in a hazard source location other than the product release location on the right of way. Liquid can flow to another location. Ignition can lead to a fire or explosion originating from this other location some distance from the release point at the pipeline. The Protocol basis scenario for a Stage 2 analysis assumes that the pool will form a circular shape at the pipeline, in the right-of-way. Consideration of the effects of topography and non-circular pools is relegated to a Stage 3 analysis. Volume 2 provides some guidance on addressing non-circular pools and pools located away from the right of way.

Another consideration for liquid releases is that the potential for fire and explosion impacts depends primarily on the surface area of the liquid pool that forms. For a leak the release rate depends on pressure as long as pumping continues. For a rupture the release depends on the pipeline bulk flow rate as long as pumping continues. In both cases the size of the pool that forms depends on the rate of release, the duration of release, and the rate of soil absorption and evaporation. These factors are incorporated into the consequence model for a liquid release. One of the first steps taken by an operator in controlling a liquid release is to shut off the product pumps at the pump station and/or close block valves on either side of the release location. Once this is done, the release discharge flow continues only if there is an elevation gradient by which liquid can continue to drain from the pipeline.

For a liquid pipeline, the released liquid pool diameter is the primary variable that determines impacts. For a given release rate, the maximum diameter of the liquid pool is determined by the type of ground surface onto which the spill has occurred and the evaporation rate. This is determined by modeling. Based on this surface area, temperatures, and wind conditions, the model calculates the vapor release rate from the pool. It then proceeds to calculate the dispersion characteristics for the LFL, pool fire impacts analogous to the jet fire impacts for gas pipelines, and the vapor cloud explosion impacts analogous to the gas cloud explosion impacts.

The same approach is used for calculating the individual hazard IR(X) and the TIR.

4.6 Consequences Estimation

This section contains data for estimating the impacts from un-ignited natural gas and flammable liquid vapor dispersion in the air after an accidental release; flash fires; natural gas jet fires; petroleum liquid pool fires; and unconfined natural gas and vapor cloud explosions. Release consequences were modeled using the air dispersion, jet fire, and explosion outputs of

EPA's ALOHA computer model (EPA 2006). Details on this model are discussed in Volume 2 of this Protocol. Tables 4-9 and 4-10 list the ALOHA input modeling parameters. Impacts were not evaluated for any distance less than 50 ft from the pipeline or hazard source for large releases. For distances this close, additional modeling should be applied, with checks by more than one estimation method, for a more detailed analysis. This would constitute a Stage 3 by definition. Near-field modeling may not accurately apply below this distance. For pipe sizes or pressures between the values shown in the impact figures from ALOHA modeling, appropriate interpolation or selection of the next higher values is used for a conservative estimate.

4.6.1 Natural Gas Release Consequences

For natural gas, the air dispersion modeling provided estimated boundaries for the lower flammability limit (LFL) for gas clouds or plumes from pipeline leaks and ruptures. The region bounded by the LFL is the region in which a flash fire or explosion could occur depending on conditions present in that zone when or shortly after a release occurs.

Jet Fires

Figures 4-6 through 4-15 present jet fire impact distances for various pipeline operating pressures and pipe sizes where the release orifice for a rupture is the pipe diameter. The graphs show impact distances for jet fires in terms of Btu/hr-ft^2 heat radiation intensity. The impact distance varies with the pipe size and pressure. For a leak rather than a rupture, the release orifice from any size pipe is represented by a 1.0-inch hole in the pipe. ALOHA modeling under the conditions for the Protocol Basis Scenarios shows an impact distance of 33 ft or less for heat radiation levels between 5,000 and 12,000 Btu/hr-ft^2 for all pipe sizes. The rate of release depends on pipeline pressure, and is independent of pipeline diameter for the leak case.

Flash Fires

Figures 4-16 and 4-17 show the computed LFL impact distances data associated with flash fires. The limits of flash fire impacts are defined in terms of the LFL boundary of a gas or vapor cloud mixed with air.

Gas Cloud Explosions

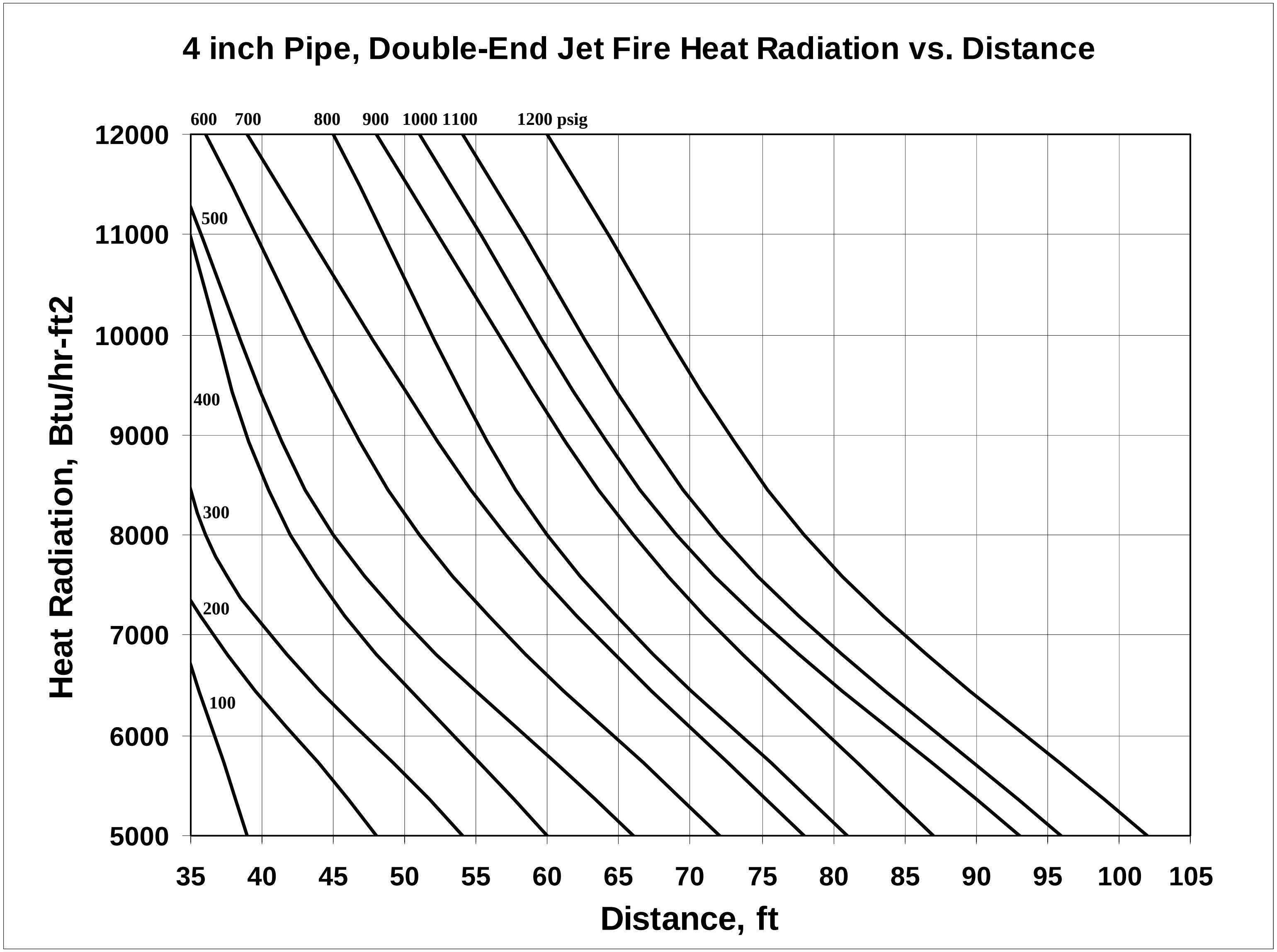
ALOHA modeling showed no potential for reaching the lower overpressure of 1.45 psi for a 1% mortality, with the pipe sizes and pressures covered by this protocol for the uncongested location option. As discussed in Volume 2, the conditions under which gas or vapor clouds can result in explosions with significant overpressures are very complex and difficult to quantify. If the risk analyst deems a school site's conditions to have sufficient congestion to significantly increase explosion a Stage 3 analysis of the explosion scenario may be appropriate. For relatively open areas, ALOHA estimates that there will be no gas cloud explosion with overpressure yielding potential fatalities. The concept of confinement, congestion, or partial congestion must be employed to generate potential overpressures and can be so site specific that reasonable representations were deemed unreasonable in the Protocol. However provision is still made within the Stage 2 framework to allow for consideration of explosions based on the opinion of the risk analyst.

Table 4-9. Pipeline Source Data Input and Rationale for ALOHA Modeling of Natural Gas and Hazardous Liquid Pipeline Releases

Parameter	Value Used		Rationale
	Gas Pipeline	**Liquid Pipeline**	
Source Type	Flammable gas burning at end of pipe; Unbroken end connected to infinite source.	Evaporating Puddle (Flash Fire); Burning Puddle (Pool Fire)	ALOHA 5.4 defaults
Species	Methane	n-Hexane	Largest constituent in natural gas
Gas Exposure Impacts	44,000 parts per million volume (ppmv)	10,500 parts per million volume (ppmv)	Assumed to be Lower Flammability Limit (LFL) of methane and n-hexane (ALOHA 5.4 default)
Flash Fire I pacts	44,000 ppmv	10,500 ppmv	Ignition occurs at Lower Flammability Limit (LFL) of methane or n-hexane (ALOHA 5.4 default)
Release Orientation	Vertical	NA	ALOHA models releases in a vertical orientation.
Pipe Roughness	Smooth	NA	Engineering judgment. Assume smooth interior surface of pipe.
Gas Pipeline Temperature	60°F	NA	Typical for buried pipes
Average Puddle Depth	NA	1 cm	OCAG default for unmitigated releases
Vapor Pressure at Atmospheric Pressure	NA	0.2 atm	ALOHA 5.4 default
Ambient Saturation Concentration	NA	20%	ALOHA 5.4 default
Initial Puddle Temperature	NA	77°F (25°C)	Same as ground temperature; ALOHA default, OCAG assumption
Ground Temperature	NA	77°F (25°C)	ALOHA 5.4 default, OCAG assumption
Ground Type	NA	Default soil	ALOHA 5.4 default
Release Duration	NA	15 min.	Typical shutdown time assumed for liquid pipelines
Air Temperature	77°F (25°C)		Engineering judgment.
Flash Fire Ignition Time	2 minutes		Data from Lees (1996) indicate most VCEs ignite within 5 minutes or less. Value selected based on report (GRI 2000) suggestion that most ignitions occur within 2 minutes, which is consistent with Lees. In ALOHA used maximum pool impact, which varied to greater times up to an hour.
Vapor Cloud Explosions Ignition Time	Can range from 5 to 15 minutes.		
Release Type	Orifice		Typical for pipeline releases
Release Hole Sizes	Full diameter; 1" Diameter		Full pipe rupture (worst case); pipe leak
Release Height	0 ft		Pipe is buried
Release Direction	Downwind		Conservative assumption
Pipeline Length	5 miles		Assumed 5 miles to block valve on either side of hole or 10 miles upstream of hole

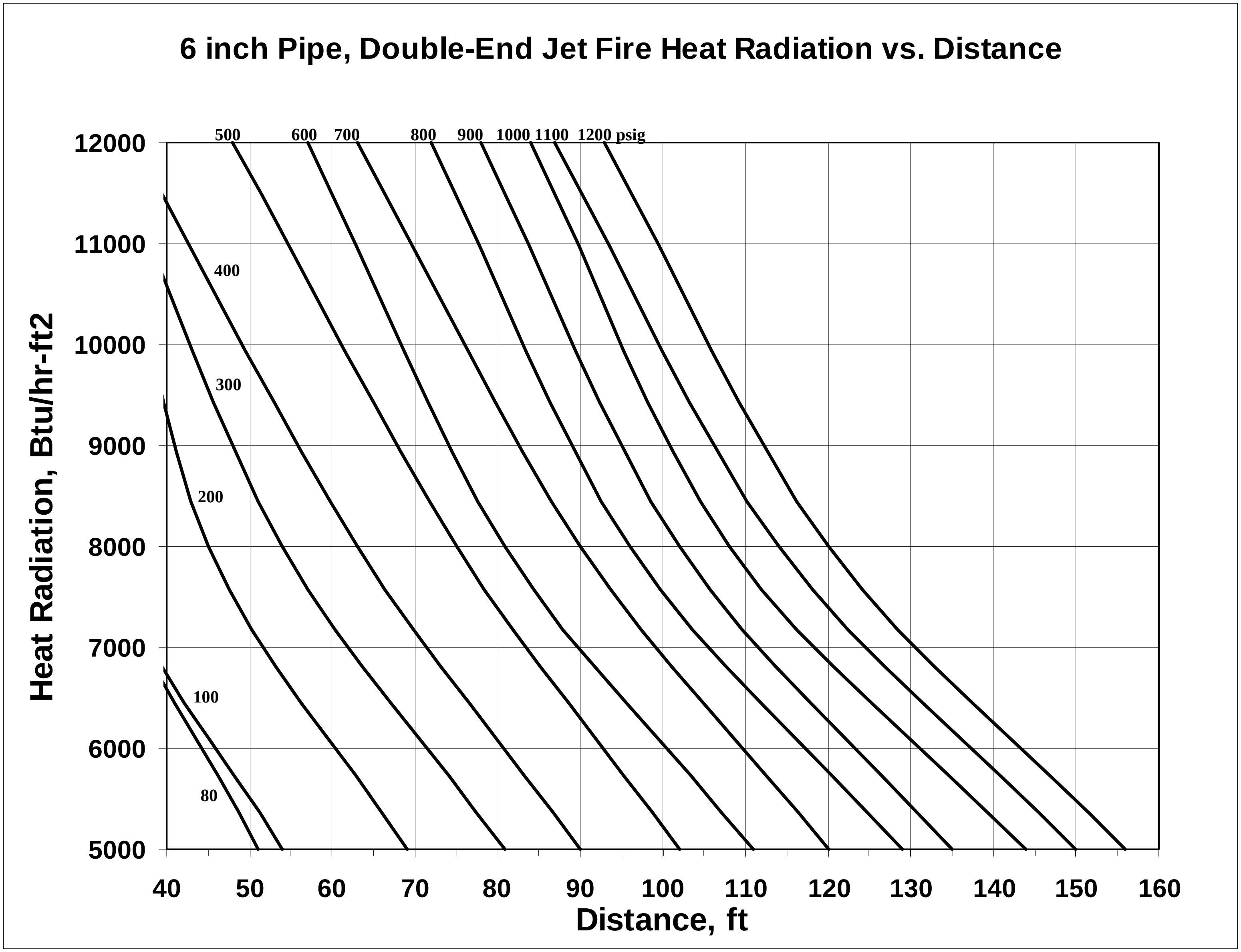
Table 4-10. Meteorological Source Data Input and Rationale ALOHA Modeling of Natural Gas and Hazardous Liquid Pipeline Releases

Parameter	Value Used	Rationale
Ambient Pressure	14.7 psi (1 atm)	Ambient conditions
Relative Humidity	50%	ALOHA 5.4 default, OCAG assumption (USEPA 1999)
Site Conditions	Rural and Urban	Both options provided in OCAG for impact distance to Lower Flammability Limit
Atmospheric Stability Class	D	ALOHA 5.4 default, OCAG assumption, alternative scenario (USEPA 1999)[a]
Cloud Cover	5 tenths	ALOHA 5.4 default
Wind Speed	6.7 miles/hr (3.0 m/s) at about a 10 ft (3 meter) height	OCAG assumption, alternative scenario (USEPA 1999)[a]
Ambient Temperature	77°F (25°C)	ALOHA 5.4 default; OCAG assumption (USEPA 1999)
Wind Direction	Directly towards school	Worst-case impact



Note: Graph curves from left to right apply for pressures of 100, 200, 300, 400, 500, 600, 700,800, 900, 1000, 1100, and 1200 psig.

Figure 4-6. Natural Gas Release Rupture Jet Fire Heat Radiation Impact, 4-inch Pipe

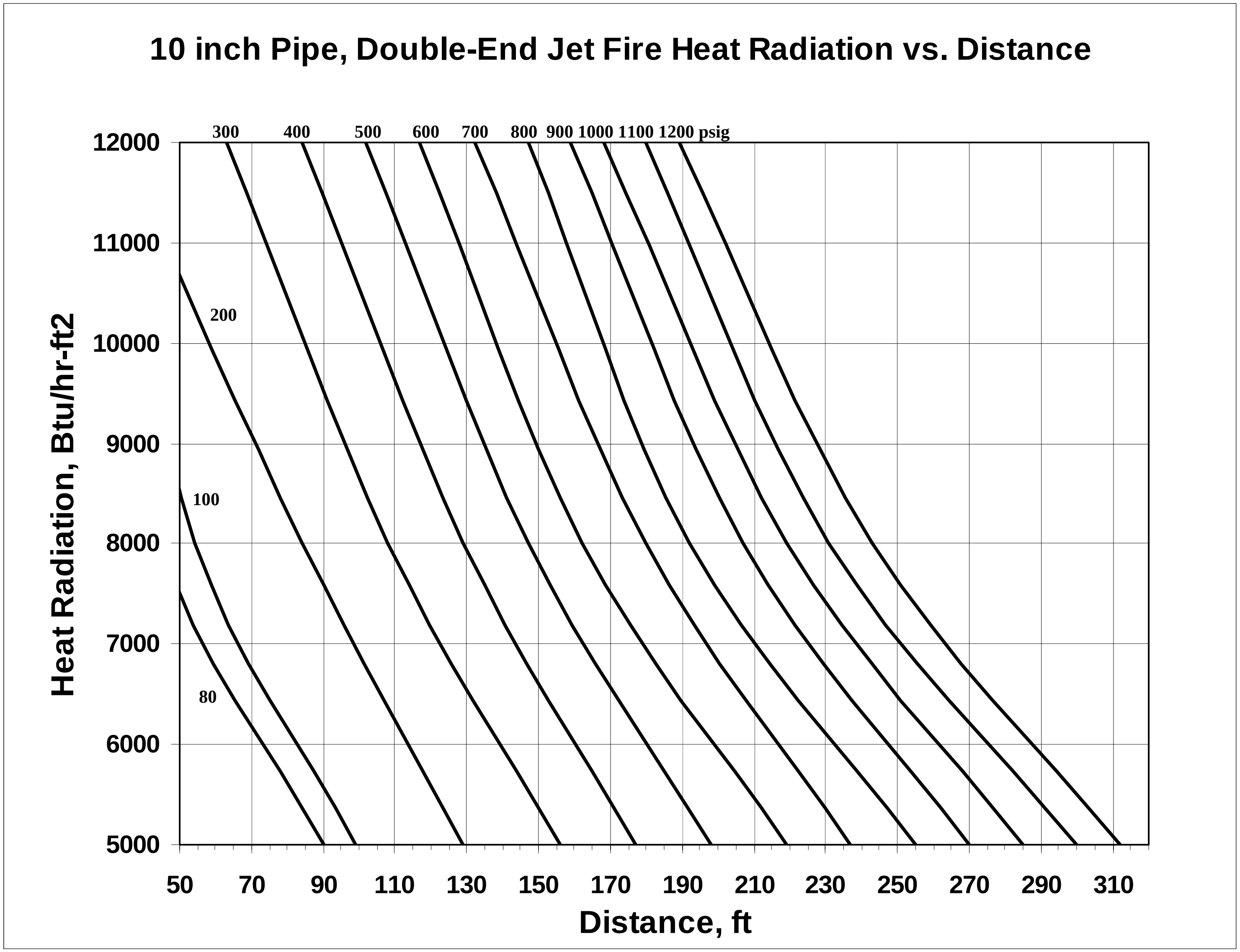


Note: Graph curves from left to right apply for pressures of 80, 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, and 1200 psig.

Figure 4-7. Natural Gas Release Rupture Jet Fire Heat Radiation Impact, 6-inch Pipe

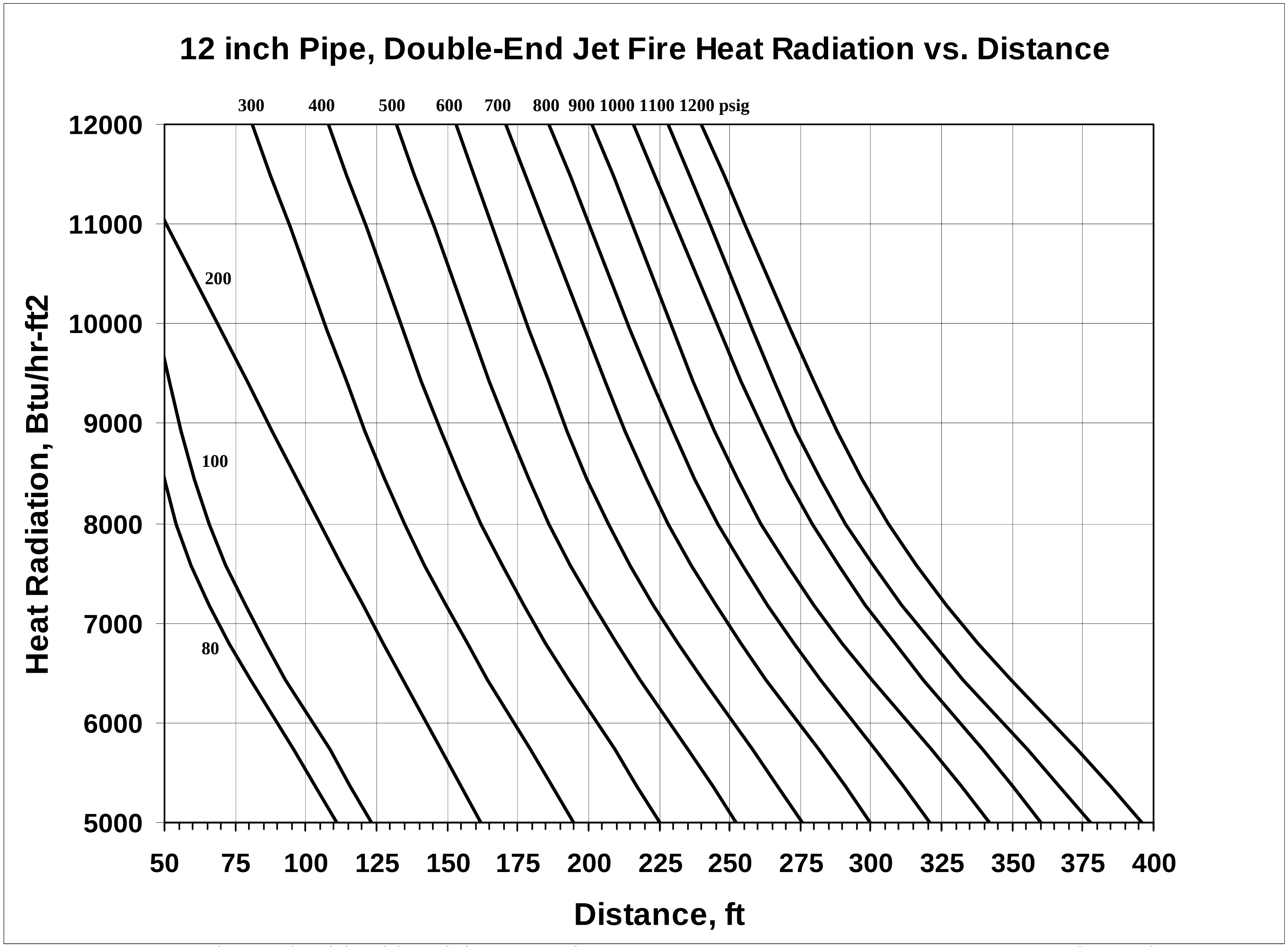
Note: Graph curves from left to right apply for pressure of 80, 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, and 1200 pisg.

Figure 4-8. Natural Gas Release Rupture Jet Fire Heat Radiation Impact, 8-inch Pipe



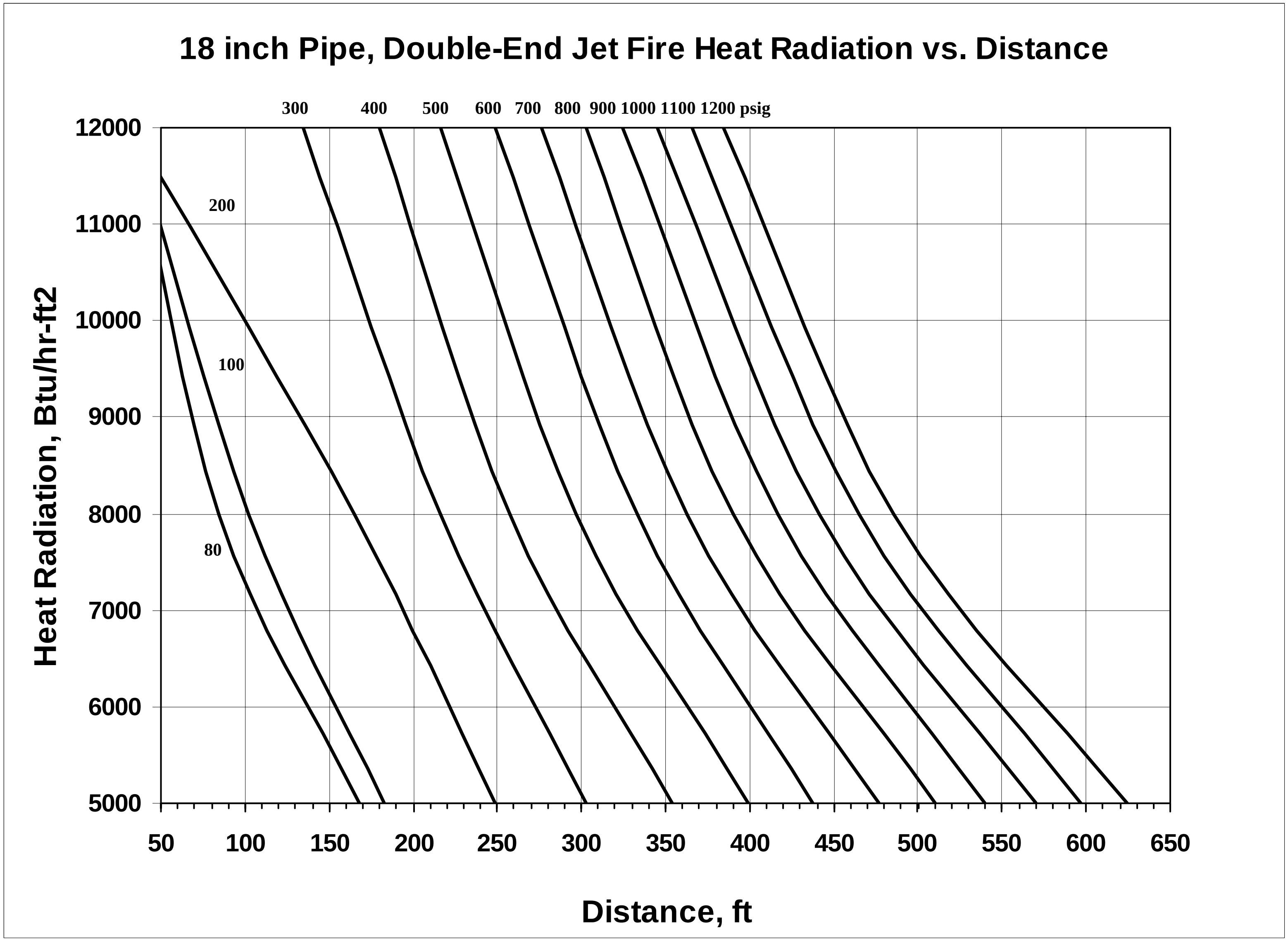
Note: Graph curves from left to right apply for pressure of 80,100, 200, 300 400, 500, 600, 700, 800, 900, 1000, 1100, and 1200 psig.

Figure 4-9. Natural Gas Release Rupture Jet Fire Heat Radiation Impact, 10-inch Pipe



Note: Graph curves from left to right apply for pressure of 80,100, 200, 300 400, 500, 600, 700, 800, 900, 1000, 1100, and 1200 psig.

Figure 4-10. Natural Gas Release Rupture Jet Fire Heat Radiation Impact, 12-inch Pipe



Note: Graph curves from left to right apply for pressure of 80,100, 200, 300 400, 500, 600, 700, 800, 900, 1000, 1100, and 1200 psig.

Figure 4-11. Natural Gas Release Rupture Jet Fire Heat Radiation Impact, 18-inch Pipe

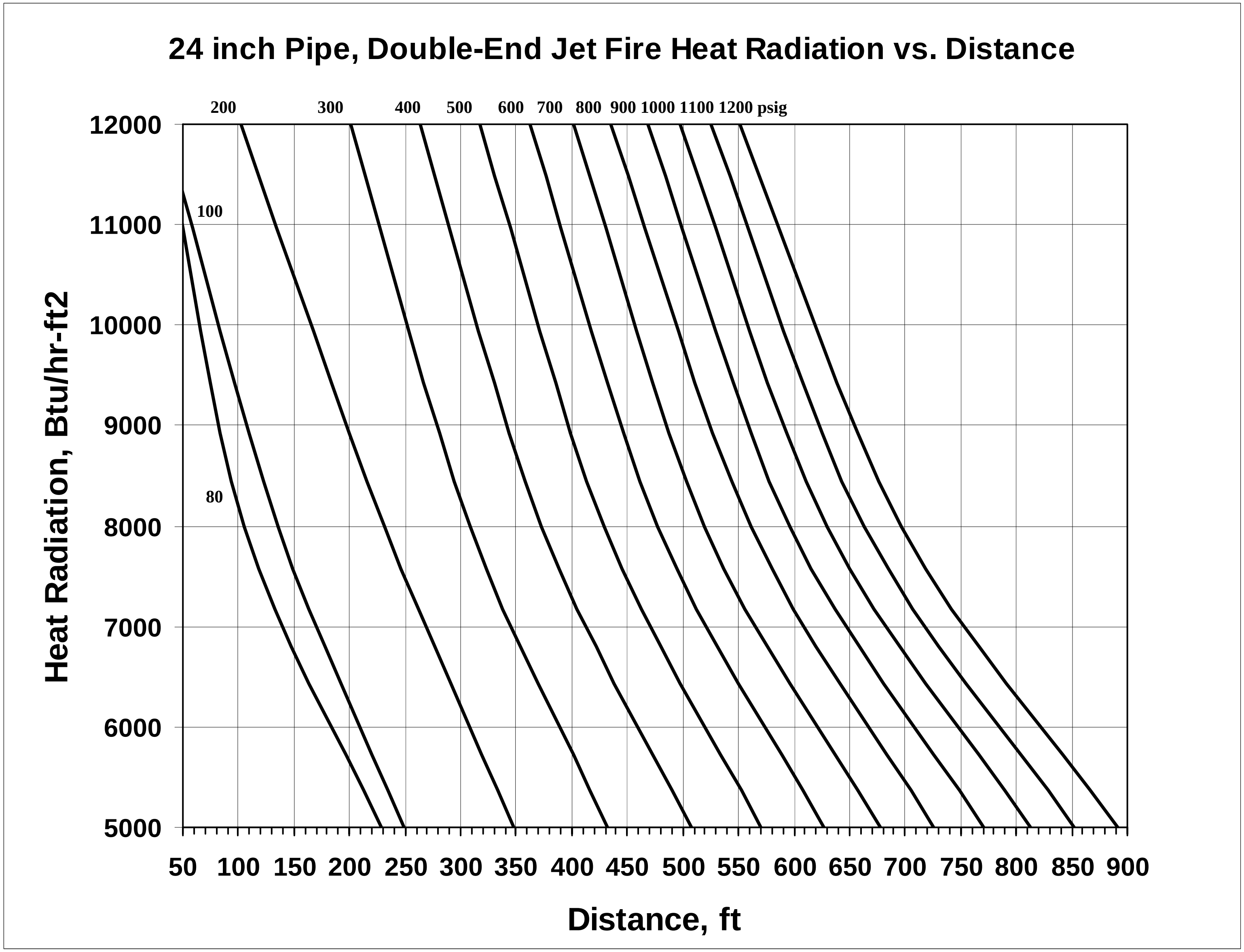


Figure 4-12. Natural Gas Release Rupture Jet Fire
Heat Radiation Impact, 24-inch Pipe

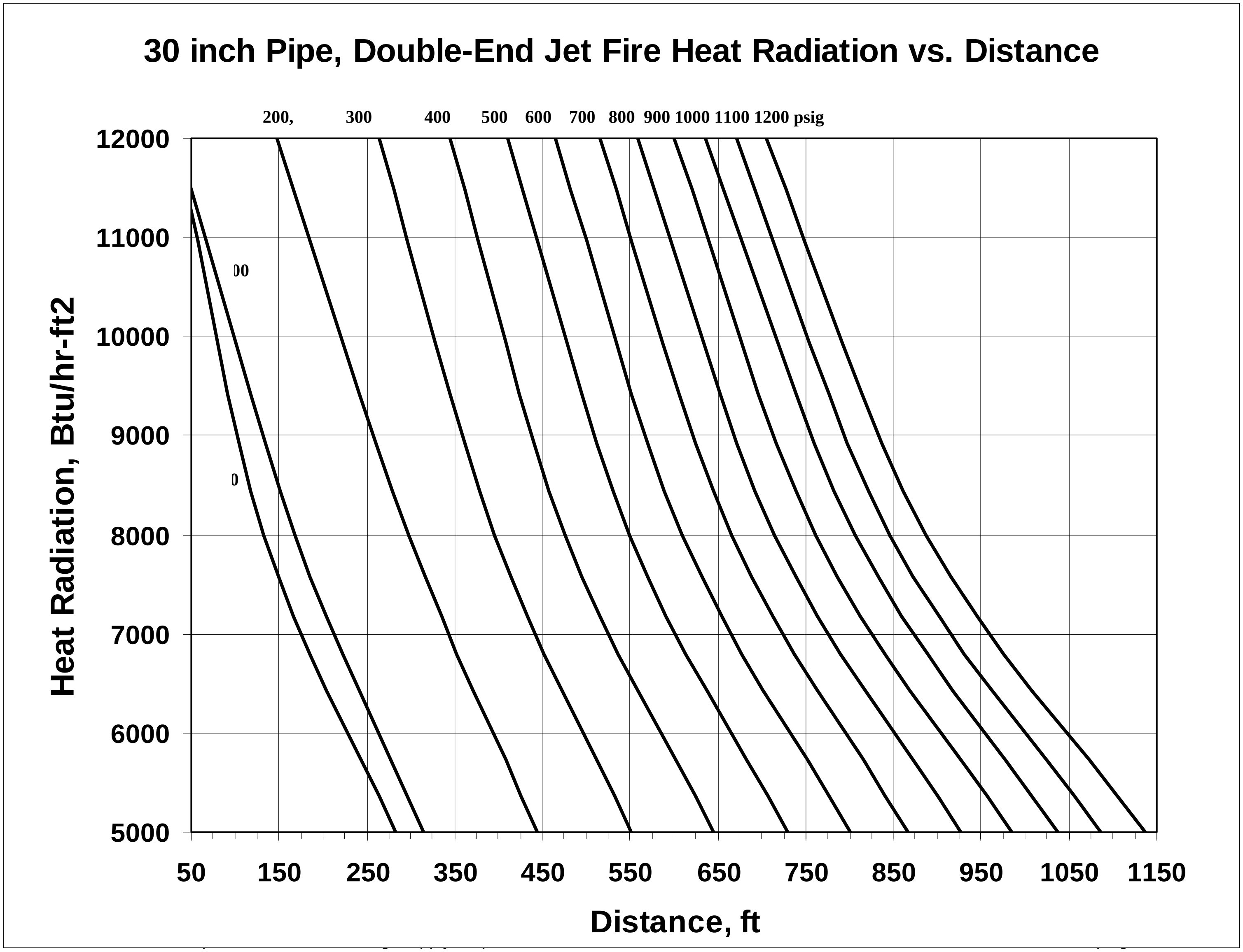
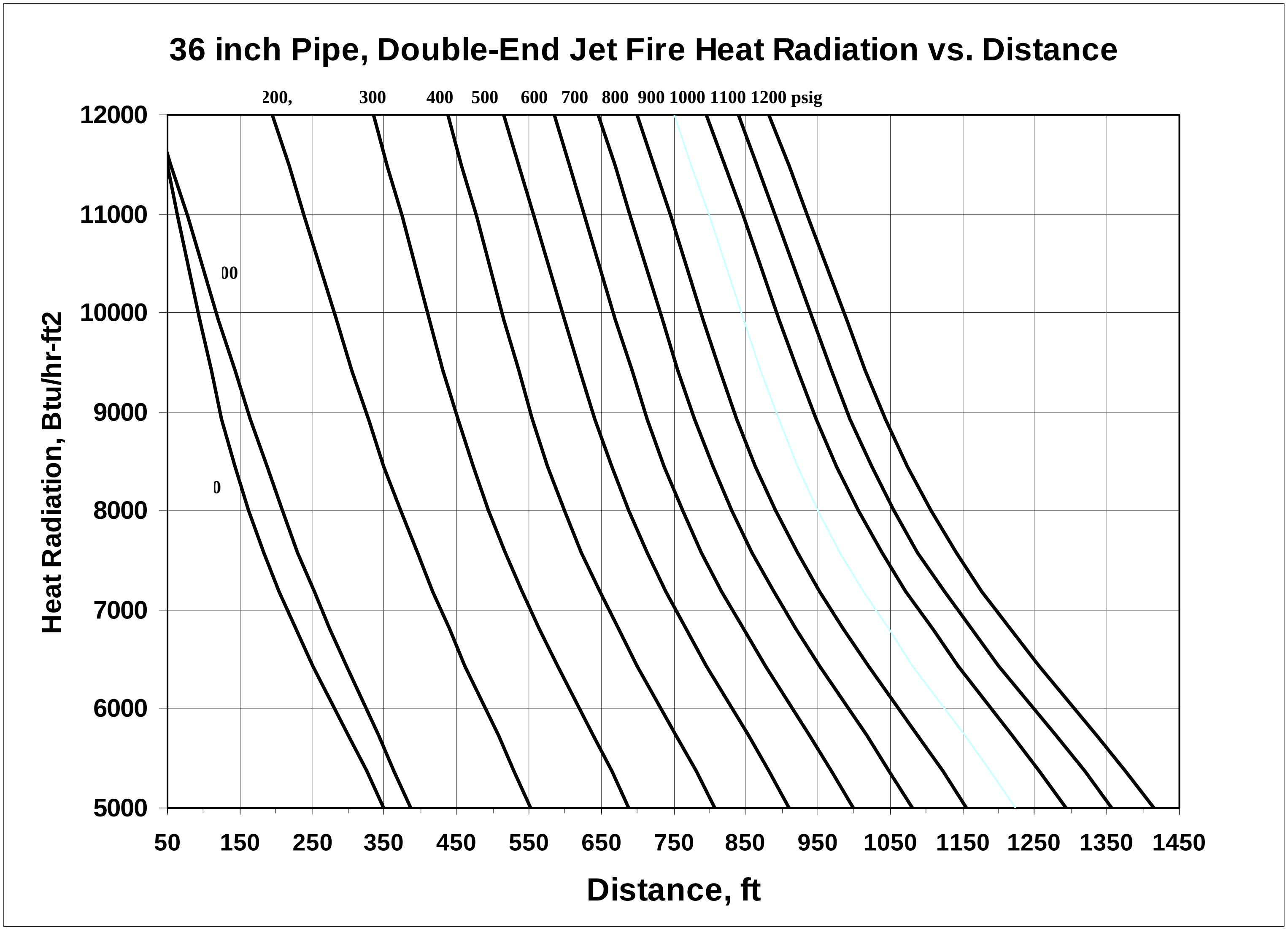
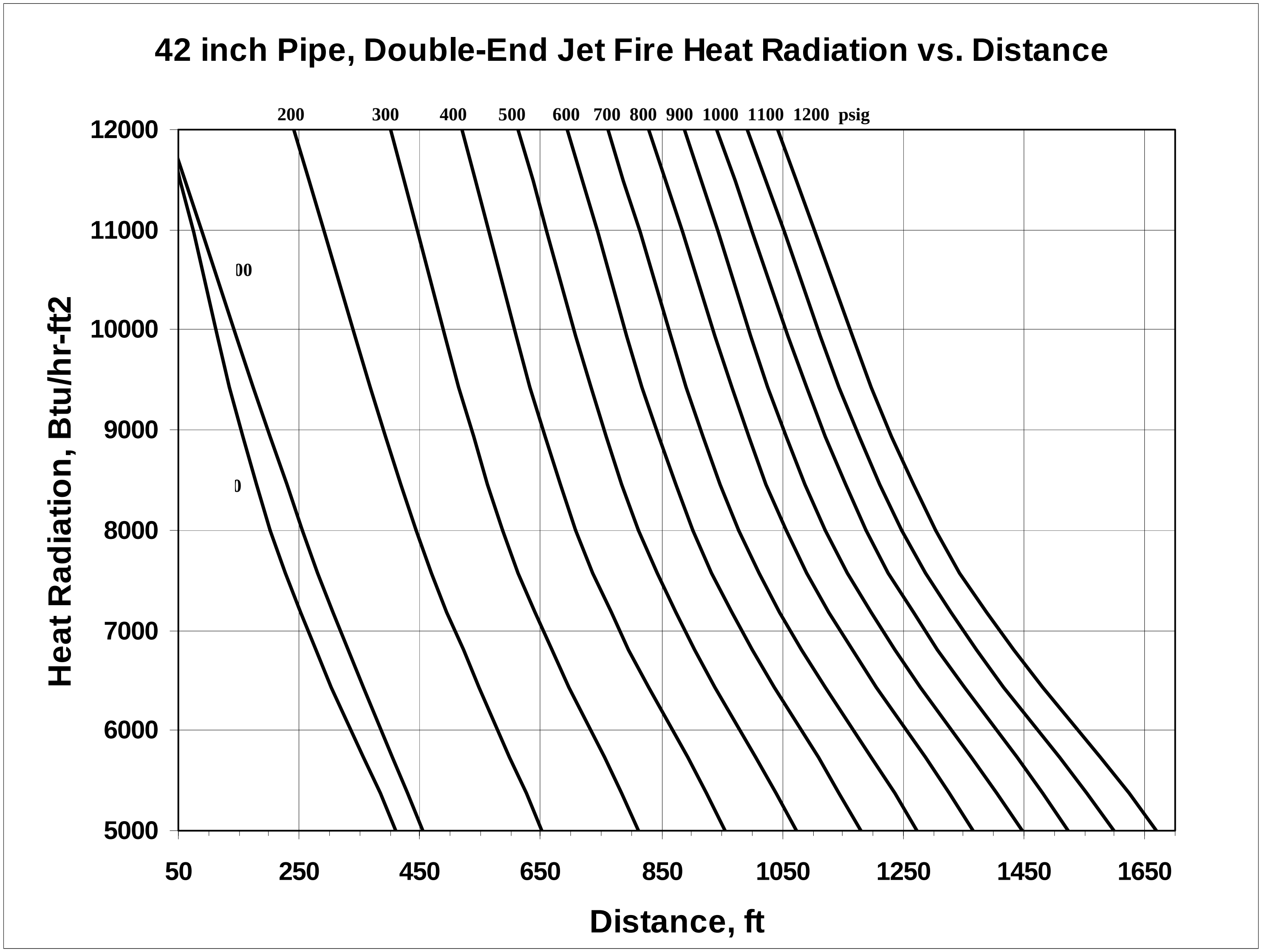


Figure 4-13. Natural Gas Release Rupture Jet Fire Heat Radiation Impact, 30-inch Pipe



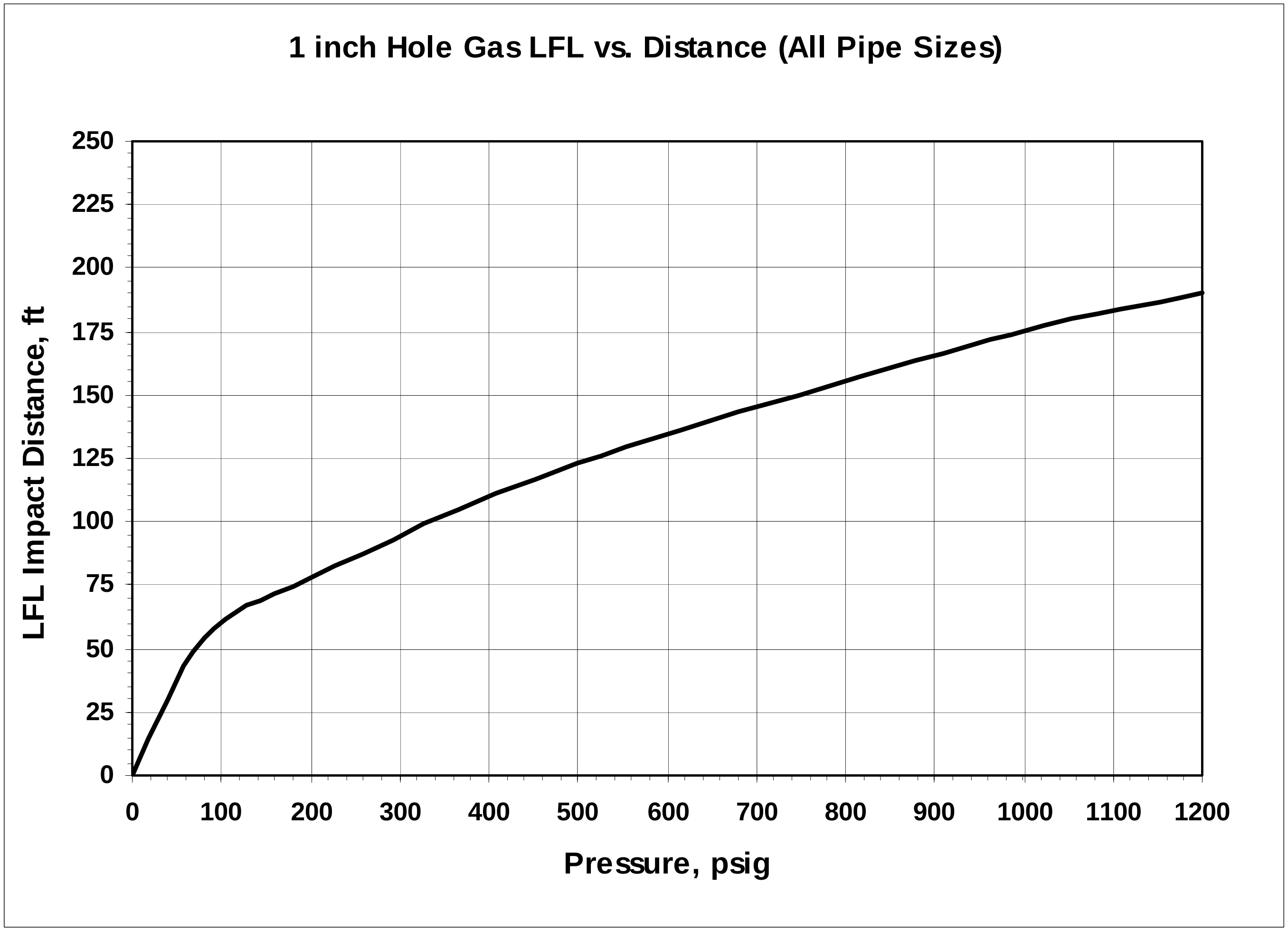
Note: Graph curves from left to right apply for pressure of 80, 100, 200, 300, 400, 500, 600, 700, 800, 900 1000, 1100, 1200, psig.

Figure 4-14. Natural Gas Release Rupture Jet Fire Heat Radiation Impact, 36-inch Pipe



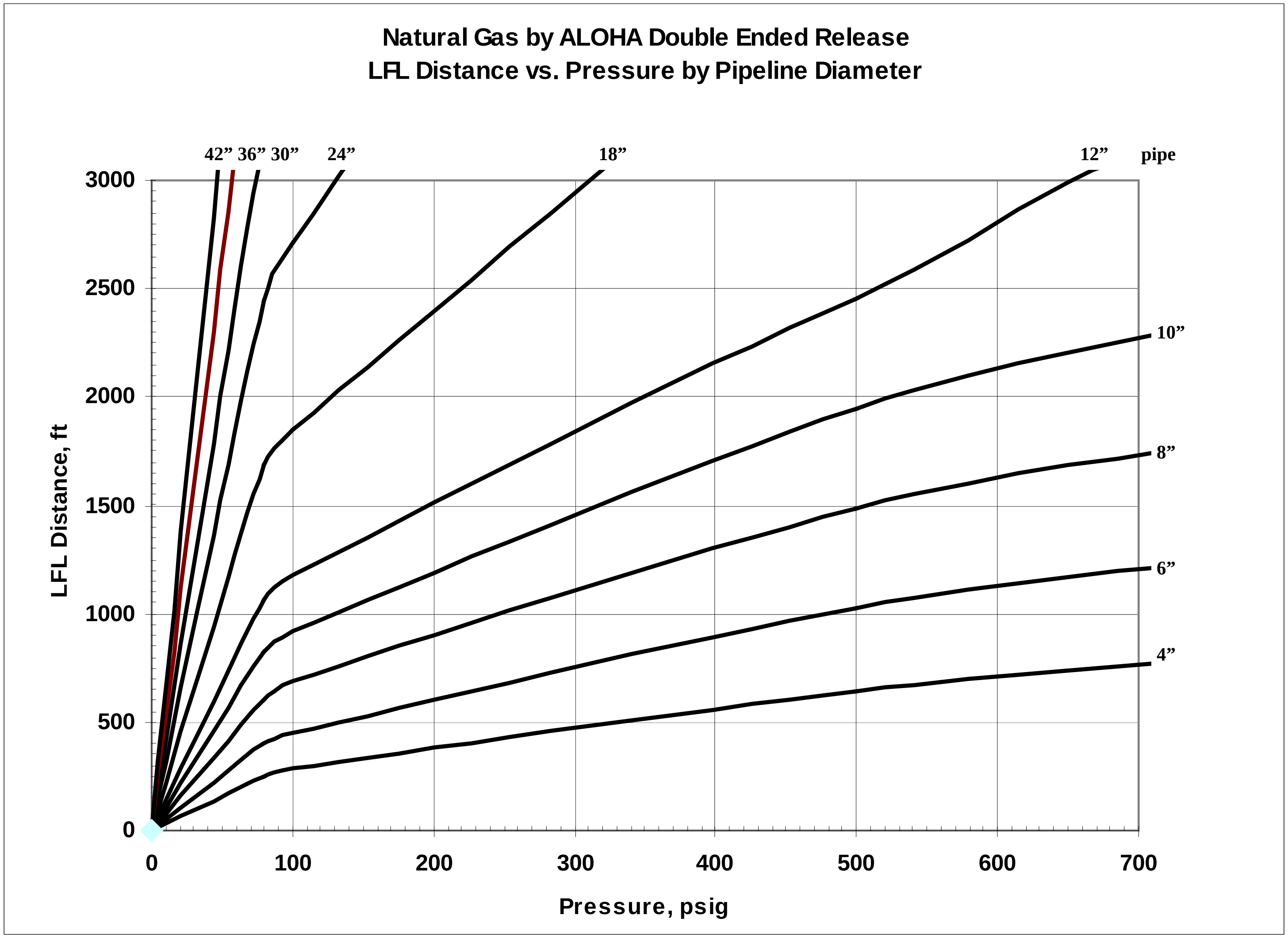
Note: Graph curves from left to right apply for pressure of 80,100, 200, 300 400, 500, 600, 700, 800, 900, 1000, 1100, and 1200 psig.

Figure 4-15. Natural Gas Release Rupture Jet Fire Heat Radiation Impact, 42-inch Pipe



Note: The 1.0 inch hole leak in a pipeline was simulated in ALOHA using a 1.0 inch hole in a vessel wall. This is because the tank wall is considered to be more representative of a leak in a pipe wall than a 1.0 inch pipe release that reflects a release from the end of a long tube. The vessel wall simulation yields a greater impact distance. Note: ALOHA does not account for the buoyancy of methane or natural gas so that modeled impact distances might also be greater than would be encountered with the actual substances, other conditions being equal.

Figure 4-16. Natural Gas Leak (1-inch hole) LFL Impact Distance



Note: ALOHA does not account for the buoyancy of methane or natural gas so that modeled impact distances might also be greater than would be encountered with the actual substances, other conditions being equal.

Figure 4-17. Natural Gas Rupture LFL Impact Distance

4.6.2 Flammable Liquid Release Consequences

The Protocol Basis Scenarios considered for liquid releases are pool fires, flash fires, and unconfined vapor cloud explosions.

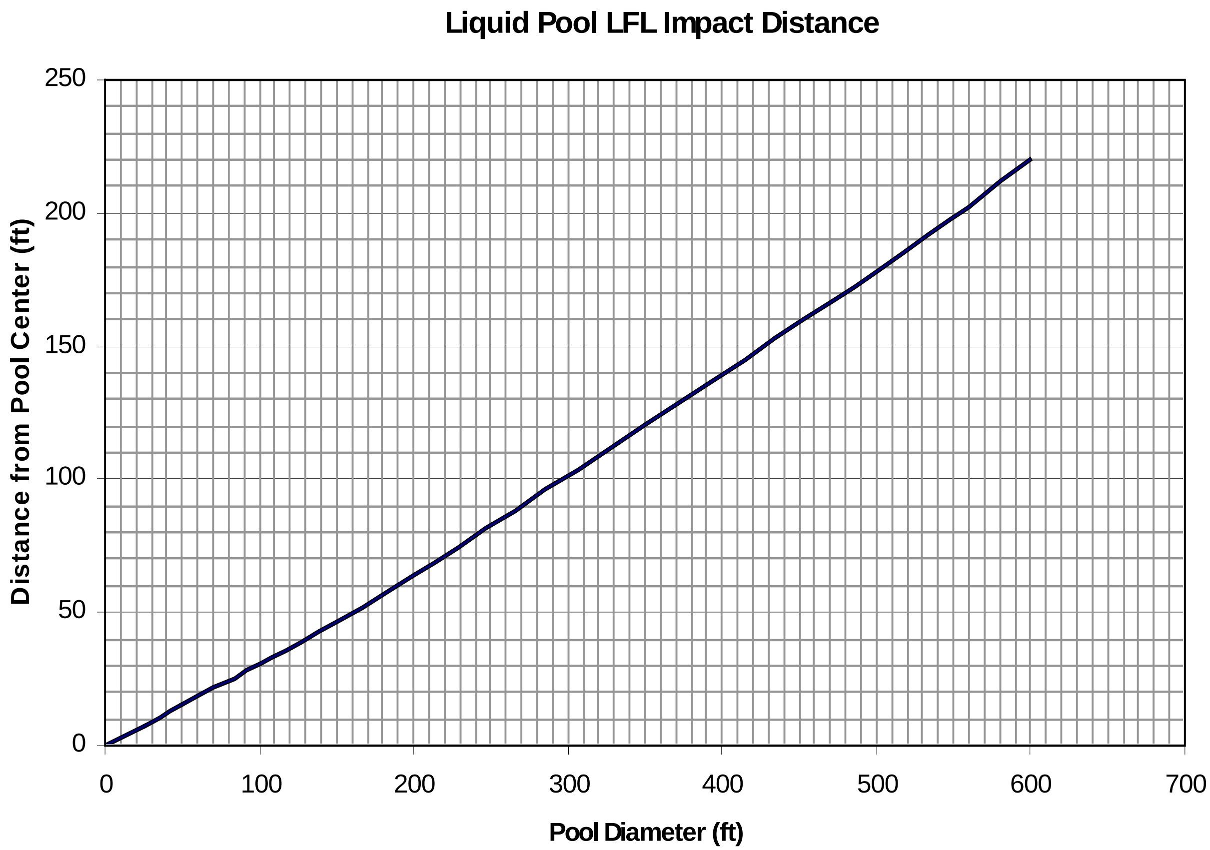
For liquid pipelines, estimating the IR follows the same general approach as for gas pipelines. However, there is an additional consideration that the hazard source could be displaced away from the right of way by overland flow of liquid. Ignition could lead to a fire or explosion originating from this other location some distance from the release point at the pipeline.

The Protocol basis scenario for a Stage 2 analysis assumes that the pool will form at the pipeline, in the right-of-way. This will apply for relatively flat locations. Consideration of the effects of topography and non-circular pools is relegated to a Stage 3 analysis. Volume 2 provides guidance on addressing non-circular pools and pools located away from the right of way.

Depending on the topography near the pipeline, between the pipeline and the school campus site, and on the campus itself, a liquid release may 1) form a pool near the pipeline release point orientated along the centerline of the pipeline (in the case of relatively flat terrain near the release point); or 2) form a flowing liquid pool that migrates away from the initial release point (in the case of significant topographic contours near the release point) toward or away from the school site.

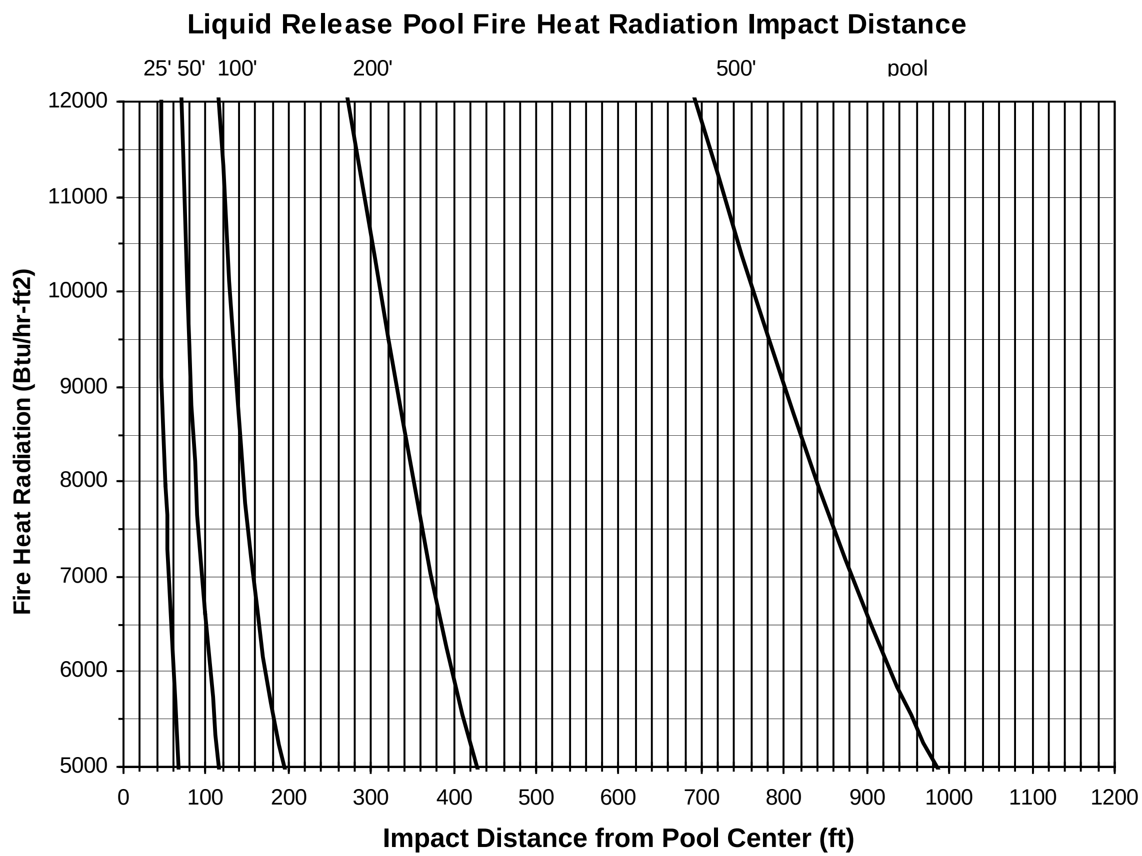
The Protocol-basis scenario assumes that the shape of the liquid pool can be approximated as either a circular area or a rectangular area located over the pipeline centerline. Circular pools or near-circular pools can be assumed to form if the flow is relatively unrestricted. A rectangular pool can be assumed to form in the case of pipelines located under a roadway where the flow is restricted by roadway curb systems. Rectangular pools are discussed in Volume 2.

Figure 4-19 presents the estimated LFL impact distance from the center of a crude oil or refined product liquid pool. These results are believed to be conservative as hexane has been used as a surrogate compound in modeling for both crude oil and gasoline vapor dispersion and ignited releases. Figure 4-20 presents the estimated pool fire impact distance from the pool



Note: Modeling was done to a 600 ft pool diameter. ALOHA does not model pools greater than 660 ft in diameter.

Figure 4-19. Liquid Release, LFL Impact Distance, Based on Circular Diameter (or Channel Equivalent Diameter)



Note: Graphs from left to right apply to pool diameters of 25, 50, 100, 200, and 500 ft.

Figure 4-20. Liquid Gasoline Release, Pool Fire Heat Radiation Impact Distance, Based on Circular Diameter (or Channel Equivalent Diameter)

center in terms of heat radiation in units of Btu/hr-ft^2. The figure applies to gasoline modeled as hexane and is to be used for all refined products. For crude oil an impact distance can be estimated as 71% of the distance shown in the figures. The basis for the differences between refined products and crude is given in a discussion in Volume 2.

Flammable vapors have the potential to ignite as an unconfined vapor cloud explosion (UCVE) special circumstances. These events are rare (Lees 1996). Similar comments apply here as in the discussion for gas cloud explosions. For the conditions modeled, ALOHA yielded no explosion overpressures for unconfined conditions. Volume 2 examines confined conditions

4.7 Other Special Considerations

4.7.1 Setback Distance for CDE IR Criterion

Given the IRC (1.0E-06), it is sometimes useful to know, for setback distance planning, when that is an option, the distance at which that criterion would occur. The method already described can be used iteratively to converge on a value for the distance corresponding to the IRC value. By selecting several widely separated distances, one can compute three values of IR. Using the three points, an IR setback distance relationship can be estimated. The data can be plotted and distance associated with the IRC estimated. Further iteration can be used to improve the estimate.

4.7.2 Population Risk Considerations

In addition to IR, some measure of potential impacts based on the population potentially at risk for the school campus site is required. This additional information aids the LEA in their site evaluation. CDE has adopted a simplified approach to evaluating impacts for the campus site in terms of two calculated parameters.

The first is the ratio of an average IR across the depth of campus site to the IR at the front property line (or boundary between the usable and unusable portion of the site when the unusable portion faces the pipeline). The second is a site population risk indicator parameter, discussed shortly. The estimates are based on dividing the site into a number of population zones. Beginning at the property line nearest the pipeline, and moving away from the property line toward the opposite side of the site, zone boundaries are established at convenient intervals, with the zone boundaries parallel to the property line. IR is evaluated at the boundaries of each zone and the IR for the site taken as the average of these zone boundary values.

For a population risk indicator, an average impact, the potentially affected population for each zone is estimated, and total affected population for the site is calculated.

For a specific hazard, CDE does not specify numerical criteria of acceptability or unacceptability for these indicators, analogous to the IRC used with the IR evaluation. Refer to Figure 4-21 for a conceptual illustration of zone and impacts definition

For illustration, Figure 4-21 shows three zones and four hazard impact circles, the radii of which define impacts on the example zone boundaries. The hazard impact is evaluated at each impact distance (e.g., R0, R1, R2, etc.). R0 corresponds to the distance from the pipeline hazard source to the property line, which also corresponds to the front boundary of the first zone. The other impact distances are the distances to the front and rear boundaries of the respective zones according to the boundaries they touch. Three zones are shown for illustration. More than three zones (e.g. five or more) might be desirable for specific sites. A greater number can improve the resolution of the indicators, especially when the population risk indicator when the distribution of the population varies significantly with the depth of the site.

For each of the six hazard impacts (leak jet fire, rupture jet fire, leak flash fire, rupture flash fire, leak explosion, and rupture explosion), the IR value or an impact can be evaluated at each of the distances. The average IR or hazard impact within a zone is determined as the average at the front and rear boundary of the zone. The IR or the hazard at each distance is evaluated based on the method discussed previously under individual risk.

The following sections illustrate this process for the average IR indicator ratio and the population risk indicator. These parameters are defined as indicator measures to characterize the risk at a site beyond the basic IR estimate, to provide further perspective on the risk taking the site area, shape, and population into account. These parameters do not replace the IR estimate, and the IR comparison with the IRC, as the primary decision criteria for evaluating a campus site.

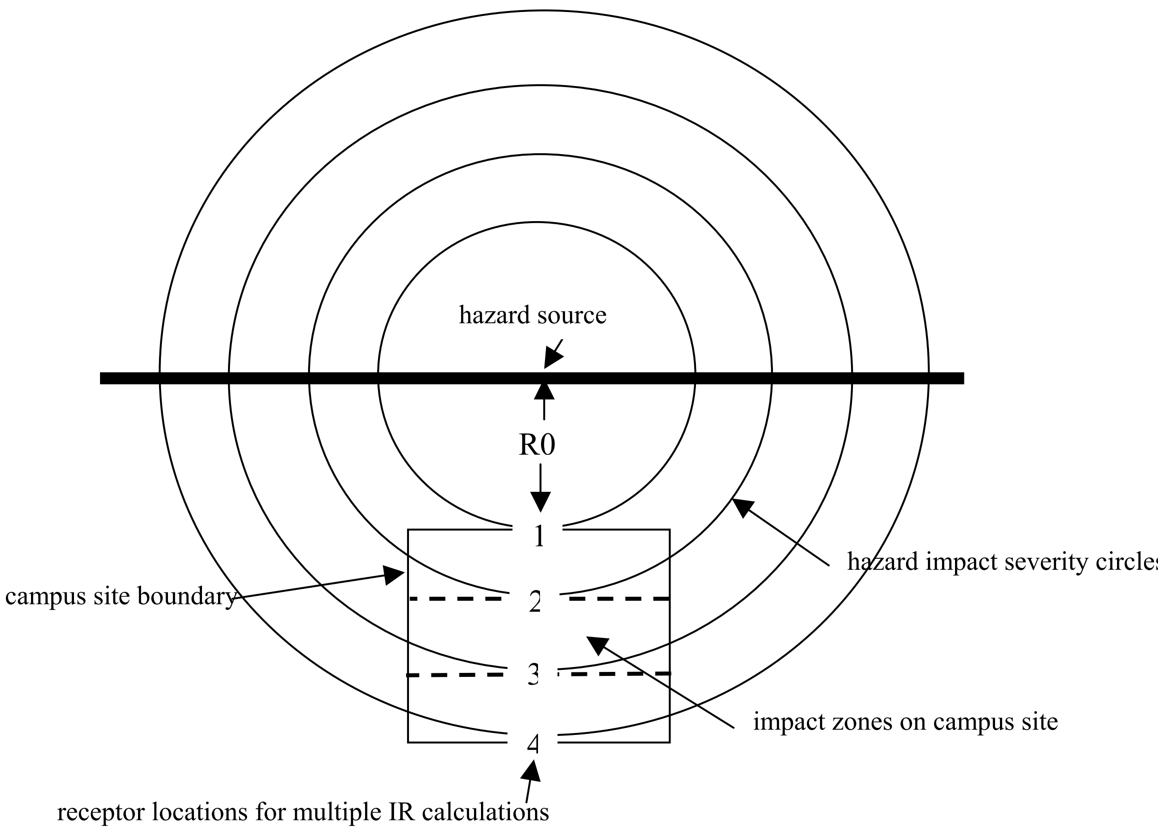


Figure 4-21. Hazard Impact Circles Corresponding to IR Values for Receptors at Boundaries of Three Impact Zones of School Campus Site

4.7.2.1 TIR Indicator Ratio

The first relative risk indicator is based on an average TIR and TIR ratio parameter for the site. To compute an estimated average TIR over the site, the TIR is first evaluated at the boundaries of the zones just described. Averaging the TIR values for the zone boundary locations yields an overall average TIR for the site (neglecting lateral variations). A TIR Indicator Ratio is defined as the ratio of the Average TIR to the front property line TIR:

TIR Indicator Ratio = TIR(AVG) / TIR (FRONT PROPERTY LINE)

This provides a measure of how rapidly the TIR decreases as one crosses the campus site and is therefore an indirect measure of how much risk the site population faces. The smaller the value, the less risk to the population for a given property line TIR. Table 4-11 shows the results for a gas pipeline example, where the front property line is 250 ft from the pipeline, the site has three zones, and boundary distances from the pipeline are shown in the table. The TIR at the various zone boundaries are shown in the table. Values are for illustration only. The TIR Indicator Ratio = 3.9E-08 / 9.8E-08 = 0.40.

Table 4-11. Average TIR Index Example for a Gas Jet Fire

Zone Boundary	Boundary Distance from Pipeline (ft)	TIR
Begin zone 1 (front property line)	250	9.8E-08
Begin zone 2	400	4.9E-08
Begin zone 3	650	4.7E-09
Back property line	850	4.7E-09
	Average TIR	**3.9E-08**
	TIR Indicator Ratio	**0.40**

4.7.2.2 Population Risk Indicator

A second measure of the relative risk to the campus site population is the potential mortality number for a given hazard scenario. The impact of the scenario is computed for the same zones defined above for the TIR. The hazard impact is evaluated at the front and rear boundary of each zone, in the same manner as for the TIR analysis. However, the maximum impact from the hazard source is evaluated at the center of each zone boundary. The corresponding mortality values are determined. The arithmetic average of the front and rear boundary mortality values for each zone is taken as the average mortality for the zone. The lateral variation across the zone is neglected to simplify the analysis. The average probability corresponding to the mortality (as a percentage) for the zone is the mortality divided by 100. The average probability for the zone multiplied by the zone population yields the estimated number of persons at risk for the zone. For simplicity in the indicator calculation, a uniform average outdoor population of 30% of the total campus site population is assumed to be distributed evenly across the zones. The 30% is based on a CDE estimate of average individual minutes spent outdoors for all grade levels (e.g., including before and after school, recess, lunch, outdoor physical education, and passing time between periods). The actual percentage for a school campus site should be used if the actual value is available.

An example uses the same parameters as in the previous TIR example calculation. Consider a school campus site with a property line 250 ft from a 30-inch, 400 psig pipeline. Assume a site depth of 600 ft and a population of 1000 persons. The assumed outdoor population during the course of site occupancy is 30% of the site population or 300 persons. For 3 zones the individual zone population is 300/3 = 100 persons per zone. For the 600-ft property depth, the depth of each of the 3 zones zone is 200 ft.

An average fatality probability in each zone is calculated as the average of the probability at the front and rear boundaries of each zone.

The results of each zone are summed to yield a Population Risk Indicator (PRI) defined by this process. The PRI is essentially a conservative, indicative measure of campus site aggregate population threat by the presence of the pipeline <u>if</u> the defined scenario were to occur. Because of the simplifications made in the calculation, the result is referred to as a risk indicator rather than a risk estimate. For purposes of this evaluation in the Protocol, the potential population impacts are evaluated only for the rupture jet fire (or pool fire for liquids) scenario, the more likely dominant hazard for pipeline risk.

Results for this example are presented in Table 4-12.

Table 4-12. Example Population Risk Indicator for Gas Release with Gas Jet Fire

Zone	**Distance from Pipeline (ft)**		**Zone Boundary Mortalities (RJF) (%)**		**Simple Avg. Zone Mortality (RJF) (%)**	**Zone Population**	**Population Risk Indicator**
	Begin	End	Begin	End			
1	250	450	100	61	80	100	80
2	450	650	61	1	31	100	31
3	650	850	1	0	0	100	0
				Population Risk Indicator			**111**

Clearly, the result depends heavily on the assumptions about the population distribution by zone. As an indicator of population risk, taking 30% of the population and distributing it in the manner noted was considered a reasonable approach for providing an indicator of risk for a school campus population. Judgment should be used in choosing the number of zones and population distributions to provide a reasonable profile of population risk

4.7.3 Multiple Pipelines

Campus sites can have multiple pipelines within the 1500-ft zone. These pipelines commonly carry different products. The approach used in the risk analysis for a single pipeline must be applied to each pipeline. The total annual risk can conservatively be estimated as the sum of the risk for all the lines. This is not the same as the risk from the simultaneous failure of lines. The latter refers to the potential for the failure of one line to occur at the same time as an event on another line. The former refers to two independent events that could occur in the same year, but at different times.

The probability for two or more independent simultaneous events is approximately the mathematical product of the probabilities for the two events. These probabilities are so low that this case is not considered as the basis for the risk analysis required by the Protocol.

Another possibility for simultaneous events is that the events are dependent, sharing a common cause. In this case, the probability of simultaneous events is not the product of the individual probabilities. Of interest is the possibility that the failure of one pipeline might cause the failure of another. To the knowledge of the authors, in the historical record, there are no cases of the reportable incident failure of one pipeline in the right of way being the cause of a reportable incident failure for another pipeline in a right-of-way. The probability of such an incident is believed low enough to exclude further consideration in a risk analysis required under this Protocol.

4.7.4 Storm Drains

Storm drains present a special case of consequence analysis not defined in the standard impacts covered by the lookup tables or graphs in this Protocol. The primary issue with storm drains is the hazard from flammable vapors from liquid spills into drains. This is a site-specific situation, which requires analysis of the potential for spillage into a storm drain system near the school. Modeling of the effects of and potential for an explosion impact is even less certain than for the gas and vapor cloud explosions, discussed earlier. In the context of this Protocol, if storm drains are situated where they could convey a liquid spill into proximity with a school site, from a nearby pipeline within the 1500-ft zone, a Stage 3 analysis of the potential impact of a storm sewer explosion might be appropriate.

4.7.5 Stage 3 Analysis– More Detailed Probabilistic Risk Analysis

A Stage 3 risk analysis is a more detailed analysis based on site-specific pipeline operating parameters as well as other site-specific conditions, or the use of more detailed models or data than is provided in this Protocol for a Stage 2 analysis. In some cases a Stage 3 analysis might be only slightly more detailed than a Stage 2. In other cases it may be much more complex. Depending on the complexity of the campus site, using the detailed modeling equations presented in Appendix C may be sufficient for carrying out the Stage 3 consequence analysis (using site-specific input parameters in the equations instead of using the consequence graphs). In addition, the technical guidance documents cited throughout this Protocol may also facilitate a Stage 3 analysis. These guidance documents include the EPA's Offsite Consequence Analysis (OCAG), or the Center for Chemical Process Safety guidance (EPA, 1999; CCPS, 1994 and 1996).

A Stage 3 analysis may also entail using a specific computer software program to estimate the consequence impacts. There are a variety of public and proprietary computer software packages available to estimate consequence impacts. These models typically require detailed input data for key operating parameters, pipeline right of way and campus site topographical conditions, and site meteorological conditions. These models may also provide detailed output results that can be overlaid onto site maps.

Depending on the situation, the probability estimation approach presented in this guidance may be sufficient to estimate the probabilities associated with the consequences estimated using "Stage 3" consequence modeling. However, specific pipeline parameters may dictate that a Probability Adjustment Factor (PAF) be used to complete the Stage 3 risk analysis. If this adjustment factor is insufficient to characterize the specific site, then more detailed probability data may be needed, which could include a review of the literature for the necessary probability data In addition, computer modeling of the consequences may also include fatality probability data.

Some cases, but not necessarily all, where a Stage 3 assessment would likely be required are:

- A site where the CDE IRC is marginal or cannot be met in a Stage 2 analysis and yet viable alternatives or mitigation measures are not available.
- The operator makes detailed information on a specific pipe segment available or results of an operator's internal risk analysis are made available.
- The pipeline carries substances other than those represented by the modeling in this Protocol.

- There is unusual land use, meteorology, topographical features or other campus site characteristics that would compromise the criteria and assumptions on which the Stage 2 process, in this Protocol, is based.
- There is a need to evaluate specific effects of mitigation measures.

4.7.6 Water Pipelines and Aqueducts

The CDE requires LEAs to evaluate high-volume water pipelines in addition to the hazardous substances already discussed. High-volume water lines are defined in this protocol as lines above at or above 12 inches in diameter, and include open aqueducts of comparable and greater volume handling capacity. The risk from water lines is associated with the potential for flooding and for subterranean erosion leading to subsidence or a sinkhole. For water lines, an evaluation of potential physical impacts for these effects is sufficient. No probability analysis is required.

A large leak or rupture of a high-volume water line will release a large quantity of water in a short time that could potentially flood adjacent areas in its drainage zone, which might involve a school campus site. The impact of this release on a school campus site depends on the local topography and location of the line. If the line is under or near a curbed road, some of the water most likely will be contained by and drain within the curbed area. For a very large release or for pipelines not under a road, depending on topography, the water can flow across parts of the school campus site. It will also drain preferentially into and through low-lying portions of the site. Table 4-13 shows estimated impact distances for two types of water release situations, assuming a water depth of 12 inches. One assumes a release on relatively flat terrain that forms a circular pool spreading from the release point. The other illustrates the effect of drainage in a channel. The channel is an example only. Other depths would yield different impact distances. Pool depth depends on local drainage conditions. The exact conditions for a specific site would be used in an actual analysis. Where the estimated impact zone poses a severe flooding threat to the school property, the site should be designed with appropriate mitigation controls.

Water released from a subterranean failure might not always migrate to the surface. It can create subterranean saturation and erosion, which can result in hazardous subsidence or even a sinkhole. The phenomena can create acute hazard for people and structures on the school campus. The threat depends on the size and location of the line relative to subsurface geological characteristics. An evaluation should be provided of potential effects, if such effects are considered plausible. It is assumed that the primary threat is in the first five minutes of the release.

Table 4-13. Estimated Water Release Impacts

Basis: average design velocity is 5 feet per second; time to shut-off is 5 minutes; drain down after shut off is assumed negligible; assumed spill pool depth is assumed to be 1.0 ft.

Diameter or Hole Size	Nominal Pipe Area	Release Rate			Release Volume	Pool Surface Area (1 ft depth)	Impact Distance for Circular Pool	Impact Distance for Rectangular Channel Width=20ft
inches	ft^2	cfs	gpm	cfm	ft^3	ft^2	ft	ft
12	0.78	3.90	1,732	234	1,170	1,170	39	59
18	1.8	8.78	3,896	527	2,633	2,633	58	132
24	3.1	15.6	6,926	936	4,680	4,680	77	234
36	7.0	35.1	15,584	2,106	10,530	10,530	116	527
48	12.5	62.4	27,706	3,744	18,720	18,720	155	936
60	19.5	97.5	43,290	5,850	29,250	29,250	194	1,463
120	78.0	390	173,160	23,400	117,000	117,000	386	5,850

cfs = cubic feet per second; gpm = gallons per minute; cfm = cubic feet per minute.

Releases are based on an assumed failure of the pipe with flow from a full diameter discharge. For a pipe, the release rate is given by multiplying the pipe area by the assumed velocity in the pipe of 5 feet per second (fps). So in the above table, the 12-inch pipe with an area of 0.78 ft^2 of nominal area yields a release rate of 0.78 ft^2 x 5 fps = 3.90 fps. The total volume of the pool is given by the release rate in cubic feet per minute (cfm) multiplied by the assumed time to shut-off of 5 minutes. For example, for the 12-inch pipe case above, the release rate is 234 cfm. The release volume is 234 cfm x 5 minutes = 1170 ft^3.

The pool is assumed to be displaced by a full diameter to the school property side of the pipeline. The diameter of the pool is taken as an estimate of the impact distance. To calculate the diameter the surface area must be known. The pool area is the volume divided by depth, in this case assumed to be 1 ft (the assumed value that could be potentially hazardous if flowing swiftly). The pool area for this example is 1170 ft^3 / 1 ft = 1170 ft^2. The diameter is given by the equation for the area of a circle, where $A = \pi D^2/4$. Rearranging, D equals the square root of $4A/\pi$, which is $D = (4A/\pi)^{0.5}$. For the example calculation, $D = (4 \times 1170\ ft^2 /\pi)^{0.5} = 39$ ft, as shown in the table. If the school site terrain is such that a channel type flow occurs away from the release, the impact distance is the pool area divided by the channel width. For the example, if the channel width is 20 ft, the impact distance D = 1170 ft^2 / 20 ft = 59 ft, as shown in the table.

Specific site conditions could lead to other pool areas and impact distances, which would have to be estimated in the manner illustrated for this example.

For an aqueduct, a breach size in the levee wall and corresponding flow rate must be determined. This can be so specific to an individual school site that no attempts are made to make generic estimates here. CDE will consider reasonable estimates of both the breach size and corresponding estimates of flow rate and flooding pool size provided by the analyst, with appropriate justification.

4.7.7 Uncertainty

As in all estimates, the uncertainties in the data and introduced in necessary assumptions result in uncertainty in the final estimates. Uncertainties arise in several data categories including the following:

- System Data
  - Inaccurate drawings and maps
  - Inaccurate specifications
- Hazard Identification
  - Hazard identification may be incomplete
- Probabilities
  - Average or conservative data may not represent the specific situation
  - Conditions upon which estimates are based may change
  - Limited data for default even probabilities
- Consequence analysis
  - Uncertainties in modeling
  - Variations in models
  - Parameters selection
  - Uncertainties in data
  - Point source assumptions
  - Limited wind speeds
  - Local weather data may differ from averages
  - Complex terrain features may alter conditions.

The topic of uncertainty is discussed in more depth in Volume 2.